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Gears, Grinding, and Toolmaking

212 Illustrations

By
EDITORIAL STAFF
INTERNATIONAL CORRESPONDENCE SCHOOLS

GEAR CALCULATIONS
GEAR CUTTING
GRINDING
TOOLMAKING

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.
1927

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PREFACE

The volumes of the International Library of Technology are made up of Instruction Papers, or Sections, comprising the various courses of instruction for students of the International Correspondence Schools. The original manuscripts are prepared by persons thoroughly qualified both technically and by experience to write with authority, and in many cases they are regularly employed elsewhere in practical work as experts. The manuscripts are then carefully edited to make them suitable for correspondence instruction. The Instruction Papers are written clearly and in the simplest language possible, so as to make them readily understood by all students. Necessary technical expressions are clearly explained when introduced.

The great majority of our students wish to prepare themselves for advancement in their vocations or to qualify for more congenial occupations. Usually they are employed and able to devote only a few hours a day to study. Therefore every effort must be made to give them practical and accurate information in clear and concise form and to make this information include all of the essentials but none of the non-essentials. To make the text clear, illustrations are used freely. These illustrations are especially made by our own Illustrating Department in order to adapt them fully to the requirements of the text.

In the table of contents that immediately follows are given the titles of the Sections included in this volume, and under each title are listed the main topics discussed.

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GEAR CALCULATIONS

KINDS OF GEARS

SPUR GEARS

DEFINITIONS

1. A wheel that has teeth on its surface for the purpose of transmitting motion to another gear or rack is called a **gear.** There are four kinds of gears that will be considered in this Section, namely, spur gears, bevel gears, worm-gears, and spiral, or helical, gears.

2. The following definitions apply to the principal classes of gearing such as spur, bevel, and worm-gearing:

A **gear-wheel** or **gear** is a wheel that is provided with projections called *teeth*, which are so formed that they transmit a definite motion to another gear. When the teeth of a pair of gears fit into one another, or engage one another, the gears, or their teeth, are said to be **in mesh.**

A **spur gear** is a gear with teeth on its circumference, as shown at *a*, Fig. 1. The teeth *a* fit into spaces *b* and the rotation of *A* therefore rotates *B*. The spur gear is the simplest and most familiar type of gear, and the forms of its teeth are used, with certain changes, for the teeth of nearly every type of gear; therefore, a study of the subject of gear-teeth can best be begun by a study of the teeth of the spur gear.

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3. The **pitch cylinders** of spur gears are the imaginary cylinders, shown by the circles *c* in Fig. 1, that roll together with the same relative speed as the gears themselves.

Fig. 2 illustrates a part of a spur gear on which the parts of the tooth and some of the principal dimensions of the gear are named. The circle that represents the pitch cylinder is called the **pitch circle,** and the diameter of this circle is called the **pitch diameter.** When the word diameter is applied to gears, it is always understood to mean the pitch diameter, unless otherwise stated, as *outside diameter*, or *diameter at the root.*

When two gears are in mesh the line joining their centers is called the **line of centers.** The line of centers passes through the point in which the pitch circles are in contact. The **breadth,** or *width*, of a tooth is measured parallel to the axis of the gear. A **rack** is a gear in which the pitch circle has been replaced by a straight line called the **pitch line.** A **pinion** is a small spur gear. The term is used especially to apply to the smaller of a pair of gears that are in mesh.

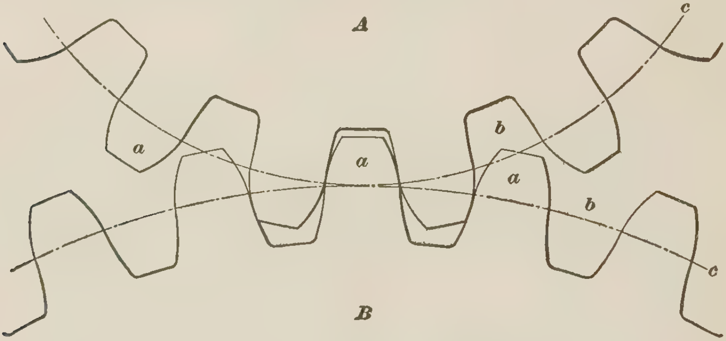

FIG. 1

4. The distance, measured along the pitch circle, from any point of one tooth to the corresponding point of the next tooth, is called the **circular pitch;** it is obtained by dividing the length of the circumference of the pitch circle by the number of teeth in the gear. The circular pitch is shown in Fig. 2.

Diametral pitch is the number of teeth per inch of pitch diameter; it is obtained by dividing the number of teeth by the pitch diameter. A gear, for example, has 60 teeth and is 10 inches in diameter; its diametral pitch is $\frac{60}{10}=6$, and the gear is therefore called a 6-pitch gear. It therefore follows that teeth of any particular diametral pitch are of the same size and have the same thickness on the pitch circle, whatever may be the diameter of the gear. Thus, if a 12-inch gear has 48 teeth, it will be 4-pitch. A 24-inch gear having teeth of the same size will have twice 48, or 96 teeth—since its circumference is twice as long—and its diametral pitch is $96 \div 24 = 4$, the same as before. Fig. 3 shows the sizes of teeth of various diametral pitches.

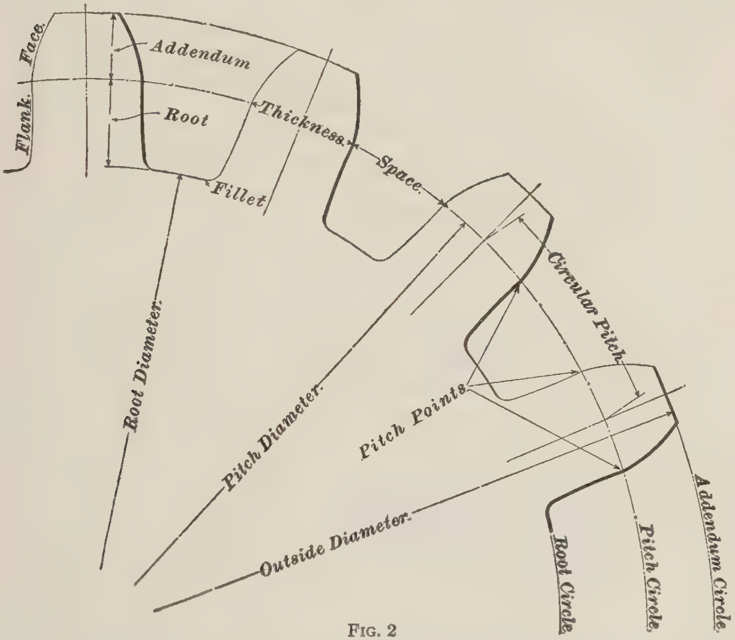

FIG. 2

5. The **addendum circle** is the circle through the extreme outer end of the gear-teeth, and the diameter of the addendum circle is the **outside diameter,** or the diameter of the **blank**

in which the gear-teeth are to be cut. The circle that forms the bottom of the spaces between the teeth is the **root**, or **dedendum, circle.** The part of the tooth outline between the pitch circle and the addendum circle is the **face** of the tooth and the **flank** is the surface from the pitch circle to the bottom of the tooth. The points in which the outline of a tooth intersect the pitch circle are called **pitch points.** The circular curve that joins the flank with the dedendum circle is a **fillet.**

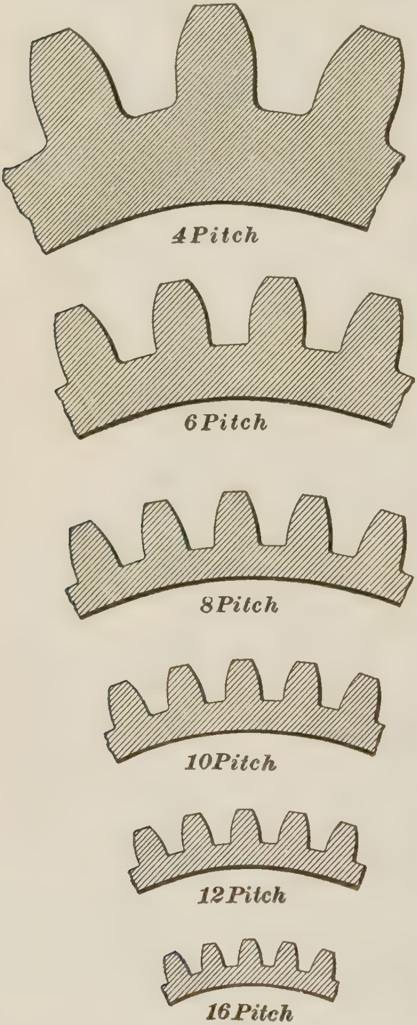

Fig. 3

6. The **addendum** is the distance between the pitch circle and the addendum circle, and the **root** or **dedendum** is the distance between the pitch and the root circles. The addendum plus the root is the **length of the tooth,** or the **depth of the cut,** and the dedendum minus the addendum is the **clearance.**

The thickness of the tooth and that of the space are each measured along the pitch circle, and their sum is the circular pitch. The difference between the width of the space and the thickness of the tooth is the **backlash.**

PROPORTIONS FOR GEAR-TEETH

7. Circular-Pitch System.—In the circular-pitch system it is customary to make the addendum, the whole depth, and the thickness of the tooth some part of the circular pitch. There is, however, no standard, and gears made in different ways require different proportions. The proportions given in Table I are sufficiently accurate for most rough gears.

TABLE I

APPROXIMATE GEAR-TOOTH PROPORTIONS FOR CIRCULAR-PITCH SYSTEM

Gear-Tooth Dimensions	Cast Gears	Cut Gears
Addendum	$.30\ p_1$	$.300\ p_1$
Root	$.40\ p_1$	$.350\ p_1$
Working depth of tooth	$.60\ p_1$	$.600\ p_1$
Whole depth	$.70\ p_1$	$.650\ p_1$
Clearance	$.10\ p_1$	$.050\ p_1$
Thickness of tooth	$.48\ p_1$	$.495\ p_1$
Width of space	$.52\ p_1$	$.505\ p_1$
Backlash	$.04\ p_1$	$.010\ p_1$

In Table I, p_1 represents the circular pitch in inches. The proportions given in the first column are suitable for cast gears and those in the second column are suitable for cut gears. Very large cast gears or gears in which the tooth outline will probably be more than ordinarily irregular may require more backlash than is given in the first column. The backlash may be increased by reducing the thickness of the tooth and increasing, by the same amount, the width of space. Cast gears and cut gears that require special cutters are usually measured and proportioned by the circular-pitch system.

EXAMPLE.—What are the tooth dimensions of a cast gear having a circular pitch of $1\frac{1}{2}$ inches?

Solution.—According to the proportions given in the first column of Table I, the tooth dimensions are:

Addendum = .3 × 1.5 = .45 inch
Root = .4 × 1.5 = .6 inch
Working depth = .6 × 1.5 = .9 inch
Whole depth = .7 × 1.5 = 1.05 inches
Clearance = .1 × 1.5 = .15 inch
Thickness of tooth = .48 × 1.5 = .72 inch
Width of space = .52 × 1.5 = .78 inch
Backlash = .04 × 1.5 = .06 inch

8. Diametral-Pitch System.—Gears of the size found in usual practice are commonly cast gears proportioned according to the diametral-pitch system. Table II gives the proportions for teeth of this system. In this table, p represents the diametral pitch.

TABLE II

GEAR-TOOTH PROPORTIONS FOR THE DIAMETRAL-PITCH SYSTEM

Gear-Tooth Dimensions	For Cut and Cast Gears
Addendum	$1 \div p$
Root	$9 \div 8p$
Working depth of tooth	$2 \div p$
Whole depth	$2.125 \div p$
Clearance	$0.125 \div p$
Thickness of tooth	$1.57 \div p$

Example.—What are the tooth dimensions of a 2-pitch gear?

Solution.—According to the proportions given in Table II, the tooth dimensions are:

Addendum = 1 ÷ 2 = .5 inch
Root = 9 ÷ (8 × 2) = .5625 inch
Working depth = 2 ÷ 2 = 1 inch
Whole depth = 2.125 ÷ 2 = 1.0625 inches
Clearance = .125 ÷ 2 = .0625 inch
Tooth thickness = 1.57 ÷ 2 = .785 inch

9. Relation Between Circular Pitch and Diametral Pitch.—The product of the circular pitch of a gear and its diametral pitch is always the constant number 3.1416. This number is one that will be used frequently in this Section. It is the number by which the diameter of a circle is multiplied to obtain the length of the circumference or by which the circumference is divided to obtain the length of the diameter. In applying the rules given in the following articles, care must be taken to perform the mathematical operations in the proper order. Multiplication and division must be performed before either addition or subtraction unless the numbers that are to be added or subtracted are enclosed in a parenthesis, in which case the operations indicated inside of the parenthesis should be performed first. The following rules tell how to change either pitch into the other pitch:

Rule I.—*To change circular pitch to diametral pitch, divide 3.1416 by the circular pitch.*

Example 1.—If the circular pitch is .3927 inch, what is the diametral pitch?

Solution.—According to the rule just given, the diametral pitch is

$$\frac{3.1416}{.3927} = 8. \quad \text{Ans.}$$

Rule II.—*To change diametral pitch to circular pitch, divide 3.1416 by the diametral pitch.*

Example 2.—If the diametral pitch is 4, what is the circular pitch?

Solution.—By the rule just given, the circular pitch is

$$\frac{3.1416}{4} = .7854 \text{ in.} \quad \text{Ans.}$$

These two statements may be conveniently remembered by the following simple relation: 3.1416 divided by either pitch gives the other pitch. For example, 4 diametral pitch corresponds with a circular pitch of .7854 inch. If the diametral pitch were given, the corresponding circular pitch would be $3.1416 \div 4 = .7854$ inch. On the other hand, if the circular pitch were given, the corresponding diametral pitch would be $3.1416 \div .7854 = 4$.

SPUR-GEAR CALCULATIONS IN THE CIRCULAR-PITCH SYSTEM

10. To Find the Addendum.—The addendum of a tooth may be found by the following rules when the circular pitch, or the outside diameter and the number of teeth, or the pitch diameter and the number of teeth are known:

Rule I.—*To find the addendum when the circular pitch is known, multiply the circular pitch by 1÷3.1416, or .3183.*

Example 1.—What is the addendum in a gear having a circular pitch of .7854 inch?

Solution.—Applying the rule just given, the addendum is

$.7854 \times .3183 = .24999$, which is practically .25 in. Ans.

Rule II.—*To find the addendum of a gear when the outside diameter and the number of teeth are known, divide the outside diameter by the number of teeth, plus 2.*

Example 2.—What is the addendum of a gear having an outside diameter of 10.5 inches and in which there are 40 teeth?

Solution.—Applying the rule just given, the addendum is

$10.5 \div (40+2) = .25$ in. Ans.

Rule III.—*To find the addendum of a gear when the pitch diameter and the number of teeth are known, divide the pitch diameter by the number of teeth.*

Example 3.—What is the addendum of a gear having a pitch diameter of 10 inches and in which there are 40 teeth?

Solution.—Applying the rule just given, the addendum is

$10 \div 40 = .25$ in. Ans.

The *flank* of the tooth is the same length as the addendum and may therefore be found by the use of the formulas just given.

11. To Find the Pitch Diameter.—When the circular pitch and the number of teeth, or the outside diameter and the number of teeth, or the depth of cut and the number of teeth are known, the pitch diameter may be found by the following rules:

Rule I.—*To find the pitch diameter when the circular pitch and the number of teeth are known, multiply the circular pitch by the number of teeth and by .3183.*

Example 1.—What is the pitch diameter of a gear having 40 teeth and a circular pitch of .7854 inch?

Solution.—Applying the rule just given, the pitch diameter is

$.7854 \times 40 \times .3183 = 9.9997$ in., or practically 10 in. Ans.

Rule II.—*To find the pitch diameter when the outside diameter and the number of teeth are known, multiply the outside diameter by the number of teeth and divide by the number of teeth plus 2.*

Example 2.—What is the pitch diameter of a gear that is 10.5 inches outside diameter and has 40 teeth?

Solution.—Applying the rule just given, the pitch diameter is

$10.5 \times 40 \div (40+2) = 10$ in. Ans.

Rule III.—*To find the pitch diameter when the number of teeth and the depth of the cut are known, multiply the product of the number of teeth and the depth of cut by .464.*

Example 3.—What is the pitch diameter of a gear that has 40 teeth and in which the cut is .539 inch deep?

Solution.—Applying the rule just given, the pitch diameter is

$40 \times .539 \times .464 = 10.00384$ in., or practically 10 in. Ans.

12. To Find the Outside Diameter or the Diameter of the Blank.—The outside diameter of a gear, or the diameter of the blank, is the sum of the pitch diameter and twice the addendum. The addendum may be found by multiplying the circular pitch by .3183. When the pitch diameter and the circular pitch, or the circular pitch and the number of teeth, or the pitch diameter and the number of teeth are known, the diameter of the blank may be found by the following rules:

Rule I.—*To find the diameter of the blank when the pitch diameter and the circular pitch are known, multiply the circular pitch by twice .3183 and add the pitch diameter.*

Example 1.—What is the outside diameter of a gear in which the pitch diameter is 10 inches and the circular pitch is .7854 inch?

Solution.—Applying the rule just given, the outside diameter, or the diameter of the blank, is

$$(.7854\times 2\times .3183)+10=10.499 \text{ in., or practically } 10.5 \text{ in.} \quad \text{Ans.}$$

Rule II.—*To find the diameter of the blank when the circular pitch and the number of teeth are known, multiply .3183 times the circular pitch by the number of teeth plus 2.*

Example 2.—What is the outside diameter of a gear in which there are 40 teeth having a circular pitch of .7854 inch?

Solution.—Applying the rule just given, the diameter of the blank is

$$.3183\times .7854\times (40+2)=10.4996 \text{ in., or practically } 10.5 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the diameter of the blank when the pitch diameter and the number of teeth are known, divide twice the pitch diameter by the number of teeth and add the pitch diameter.*

Example 3.—What is the outside diameter of a gear in which the pitch diameter is 10 inches and there are 40 teeth?

Solution.—Applying the rule just given, the diameter of the blank is

$$(2\times 10)\div 40+10=10.5 \text{ in.} \quad \text{Ans.}$$

13. To Find the Depth of Cut.—When the circular pitch, or the outside diameter and the number of teeth, or the pitch diameter and the number of teeth are known, the depth of the cut may be found by applying the following rules:

Rule I.—*To find the depth of cut when the circular pitch is known, multiply the circular pitch by .6866.*

Example 1.—What is the depth of cut for a gear having a circular pitch of .7854 inch?

Solution.—Applying the rule just given, the depth of cut is

$$.7854\times .6866=.539 \text{ in.} \quad \text{Ans.}$$

Rule II.—*To find the depth of cut when the outside diameter and the number of teeth are known, multiply the outside diameter by 2.157 and divide by the number of teeth plus 2.*

Example 2.—What is the depth of cut for a gear having 40 teeth and an outside diameter of 10.5 inches?

Solution.—Applying the rule just given, the depth of cut is

$$10.5\times 2.157\div (40+2)=.539 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the depth of cut when the pitch diameter and the number of teeth are known, divide the pitch diameter by the number of teeth and multiply by 2.157.*

EXAMPLE 3.—What is the depth of cut for a gear having 40 teeth and a pitch diameter of 10 inches?

SOLUTION.—Applying the rule just given, the depth of cut is

$$10 \div 40 \times 2.157 = .539 \text{ in.} \quad \text{Ans.}$$

14. To Find the Number of Teeth.—Knowing the pitch diameter and circular pitch, or the outside diameter and the circular pitch, the number of teeth may be found by the following rules:

Rule I.—*To find the number of teeth when the pitch diameter and the circular pitch are known, divide the pitch diameter by the circular pitch and multiply by 3.1416.*

EXAMPLE 1.—How many teeth are there on a gear that has a pitch diameter of 10 inches and a circular pitch of .7854 inch?

SOLUTION.—Applying the rule just given, the number of teeth is

$$10 \div .7854 \times 3.1416 = 40. \quad \text{Ans.}$$

Rule II.—*To find the number of teeth when the outside diameter and the circular pitch are known, multiply the outside diameter by 3.1416, divide by the circular pitch, and subtract 2.*

EXAMPLE 2.—How many teeth are there on a gear that has an outside diameter of 10.5 inches and a circular pitch of .7854 inch?

SOLUTION.—Applying the rule just given, the number of teeth is

$$10.5 \times 3.1416 \div .7854 - 2 = 40. \quad \text{Ans.}$$

15. To Find the Circular Pitch.—When the diameter of the blank and the number of teeth, or the pitch diameter and the number of teeth, or the depth of cut are known, the circular pitch may be found by applying the following rules.

Rule I.—*To find the circular pitch of a gear when the diameter of the blank and the number of teeth are known, divide the product of 3.1416 and the outside diameter by the number of teeth plus 2.*

EXAMPLE 1.—What is the circular pitch of a gear that is 10.5 inches outside diameter and has 40 teeth?

Solution.—Applying the rule just given, the circular pitch is

$3.1416 \times 10.5 \div (40+2) = .7854$ in. Ans.

Rule II.—*To find the circular pitch when the pitch diameter and the number of teeth are known, divide 3.1416 times the pitch diameter by the number of teeth.*

Example 2.—What is the circular pitch of a gear when the pitch diameter is 10 inches and there are 40 teeth?

Solution.—Applying the rule just given, the circular pitch is

$3.1416 \times 10 \div 40 = .7854$ in. Ans.

Rule III.—*To find the circular pitch when the depth of the cut is known, multiply the depth of the cut by 1.4565.*

Example 3.—What is the circular pitch of a gear in which the cut is .539 inch deep?

Solution.—Applying the rule just given, the circular pitch is

$.539 \times 1.4565 = .7851$ in., nearly

Owing to the dropping of decimal points, this answer is slightly less than that of example 2, but the difference is so slight that it would not ordinarily be considered.

When the diametral pitch is known, the circular pitch may be found by applying rule II of Art. **9**.

SPUR-GEAR CALCULATIONS IN THE DIAMETRAL-PITCH SYSTEM

16. To Find the Addendum.—The addendum of the teeth may be found by means of the following rules when the diametral pitch, or the pitch diameter and the number of teeth, or the outside diameter and the number of teeth are known:

Rule I.—*To find the addendum of a tooth when the diametral pitch is known, divide 1 by the diametral pitch.*

Example 1.—What is the addendum of the teeth of a 4-pitch gear?

Solution.—Applying the rule just given, the addendum is

$1 \div 4 = .25$ in. Ans.

Rule II.—*To find the addendum when the pitch diameter and the number of teeth are known, divide the pitch diameter by the number of teeth.*

Example 2.—What is the addendum of the teeth of a gear having 40 teeth on a pitch diameter of 10 inches?

Solution.—Applying the rule just given, the addendum is

$$10 \div 40 = .25 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the addendum when the outside diameter and the number of teeth are known, divide the outside diameter by the number of teeth plus 2.*

Example 3.—What is the addendum of the teeth of a gear that is 10.5 inches outside diameter and has 40 teeth?

Solution.—Applying the rule just given, the addendum is

$$10.5 \div (40+2) = .25 \text{ in.} \quad \text{Ans.}$$

17. To Find the Pitch Diameter.—When the number of teeth and diametral pitch, or the number of teeth and outside diameter, or the outside diameter and the diametral pitch are known, the pitch diameter may be found by the following rules:

Rule I.—*To find the pitch diameter when the number of teeth and the diametral pitch are known, divide the number of teeth by the diametral pitch.*

Example 1.—What is the pitch diameter of a 4-pitch gear having 40 teeth?

Solution.—Applying the rule just given, the pitch diameter is

$$40 \div 4 = 10 \text{ in.} \quad \text{Ans.}$$

Rule II.—*To find the pitch diameter when the number of teeth and the outside diameter are known, divide the number of teeth times the outside diameter by the number of teeth plus 2.*

Example. 2.—What is the pitch diameter of a 40-tooth gear that is 10.5 inches outside diameter?

Solution.—Applying the rule just given, the pitch diameter is

$$40 \times 10.5 \div (40+2) = 10 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the pitch diameter when the diametral pitch and the outside diameter are known, multiply the diametral pitch by the outside diameter, subtract 2, and divide by the diametral pitch.*

EXAMPLE 3.—What is the pitch diameter of a 4-pitch gear 10.5 inches outside diameter?

SOLUTION.—Applying the rule just given, the pitch diameter is

$$(4\times 10.5-2)\div 4=10 \text{ in.} \quad \text{Ans.}$$

18. To Find the Outside Diameter, or the Diameter of the Blank.—The following rules may be used to find the diameter of the gear-blank, when the pitch diameter and the diametral pitch, or the diametral pitch and the number of teeth, or the pitch diameter and the number of teeth are known:

Rule I.—*To find the outside diameter, or the diameter of the blank, when the pitch diameter and the diametral pitch are known, divide 2 by the pitch and add the pitch diameter.*

EXAMPLE 1.—What is the diameter of the blank for a 4-pitch gear having a pitch diameter of 10 inches?

SOLUTION.—Applying the rule just given, the diameter of the blank is

$$(2\div 4)+10=10.5 \text{ in.} \quad \text{Ans.}$$

Rule II.—*To find the outside diameter, or the diameter of the blank, when the diametral pitch and the number of teeth are known, add 2 to the number of teeth and divide the sum by the diametral pitch.*

EXAMPLE 2.—What is the diameter of the blank for a 4-pitch gear having 40 teeth?

SOLUTION.—Applying the rule just given, the diameter of the blank is

$$(40+2)\div 4=10.5 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the outside diameter, or the diameter of the blank, when the pitch diameter and the number of teeth are known, divide the product of the number of teeth plus 2 and the pitch diameter by the number of teeth.*

EXAMPLE 3.—What is the diameter of the blank for a gear having 40 teeth that is 10 inches in pitch diameter?

Solution.—Applying the rule just given, the diameter of the blank is

$$(40+2) \times 10 \div 40 = 10.5 \text{ in.} \quad \text{Ans.}$$

19. To Find the Depth of the Cut.—When the diametral pitch, or the number of teeth and the outside diameter, or the number of teeth and the pitch diameter are known, the depth of the cut may be found by the use of the following rules:

Rule I.—*To find the depth of the cut when the diametral pitch is known, divide 2.157 by the diametral pitch.*

Example 1.—What is the depth of the cut in a 4-pitch gear?

Solution.—Applying the rule just given, the depth of the cut is

$$2.157 \div 4 = .539 \text{ in.} \quad \text{Ans.}$$

Rule II.—*To find the depth of the cut when the number of teeth and the outside diameter are known, divide 2.157 times the outside diameter by the number of teeth plus 2.*

Example 2.—What is the depth of the cut in a gear having 40 teeth and an outside diameter of 10.5 inches?

Solution.—Applying the rule just given, the depth of the cut is

$$2.157 \times 10.5 \div (40+2) = .539 \text{ in.} \quad \text{Ans.}$$

Rule III.—*To find the depth of the cut when the number of teeth and the pitch diameter are known, divide 2.157 times the pitch diameter by the number of teeth.*

Example 3.—What is the depth of the cut in a gear having 40 teeth and a pitch diameter of 10 inches?

Solution.—Applying the rule just given, the depth of the cut is

$$2.157 \times 10 \div 40 = .539 \text{ in.} \quad \text{Ans.}$$

20. To Find the Number of Teeth.—The number of teeth may be found by the following rules when the diametral pitch together with either the pitch diameter or the outside diameter is known:

Rule I.—*To find the number of teeth when the pitch diameter and the diametral pitch are known, multiply the pitch diameter by the diametral pitch.*

Example 1.—How many teeth are there on a 4-pitch gear 10 inches in pitch diameter?

Solution.—Applying the rule just given, the number of teeth is

$$10 \times 4 = 40. \quad \text{Ans.}$$

Rule II.—*To find the number of teeth when the outside diameter and the diametral pitch are known, multiply the outside diameter by the diametral pitch and subtract 2 from the product.*

Example 2.—How many teeth are there on a 4-pitch gear 10.5 inches outside diameter?

Solution.—Applying the rule just given, the number of teeth is

$$10.5 \times 4 - 2 = 40. \quad \text{Ans.}$$

21. To Find the Diametral Pitch.—The diametral pitch may be found by means of the following rules when the number of teeth and the pitch diameter or the outside diameter are known:

Rule I.—*To find the diametral pitch when the number of teeth and the pitch diameter are given, divide the number of teeth by the pitch diameter.*

Example 1.—What is the diametral pitch of a 40-tooth gear 10 inches in pitch diameter?

Solution.—Applying the rule just given, the diametral pitch is

$$40 \div 10 = 4. \quad \text{Ans.}$$

Rule II.—*To find the diametral pitch when the outside diameter and the number of teeth are known, add 2 to the number of teeth and divide the sum by the outside diameter.*

Example 2.—What is the diametral pitch of a 40-tooth gear that is 10.5 inches outside diameter?

Solution.—Applying the rule just given, the diametral pitch is

$$(40 + 2) \div 10.5 = 4. \quad \text{Ans.}$$

22. Finding the Pitch From the Gear.—In using the rules given in Art. 21, by applying the dimensions taken from a gear or gear-blank, it will sometimes be found that the result obtained does not correspond with any standard pitch number; for example, suppose that a gear with 68 teeth measures $15\frac{9}{16}$ inches, outside diameter. Applying rule II, the pitch would be $(68+2) \div 15.5625 = 4.4979$; this number is so near $4\frac{1}{2}$, which is a standard pitch, that it is evident that $4\frac{1}{2}$ is the pitch of the gear and that either the blank was not turned to the exact diameter called for by the pitch and number of teeth or the diameter was not measured accurately. When a set of standard cutters are available, the pitch of the gear can also be determined by trying different cutters until one is found that fits.

A considerable difference between the value obtained by applying the rule and the nearest standard pitch will indicate that an uncommon pitch has been used. In general, however, it may be assumed that the pitch is the standard whose number agrees most nearly with the value obtained from an application of the rule.

As far as practicable, the pitch and diameter should be so chosen that the number of teeth will correspond with the number of divisions that can be readily obtained with the aid of the indexing mechanism of the machine in which the gear is to be cut.

LAYING OUT GEAR-TEETH

23. Smooth-Running Gears.—When it is desired to have gears operate smoothly and quietly, a constant relation must be maintained between the speed of the driver and that of the driven gear. In order to obtain smooth-running gears, it is necessary that the tooth outline fulfil certain conditions. Inaccuracies in the tooth outline will not affect the number of revolutions per minute of the driven gear but will cause variations in its speed only while the inaccurate teeth are in action. Variations of this kind are more noticeable when the gears operate at high speeds than at low.

The condition that the gear-teeth must fulfil in order that the gears may operate smoothly and quietly is most easily explained by reference to Fig. 4. This figure shows a portion of two gears in mesh. The line of centers is shown at *a a* and gear *A* is supposed to be driving in the direction shown by the arrow. Teeth *b* and *c* will be used in this explanation, although any other pair that is in action would illustrate the same points. Tooth *b* is in contact with tooth *c* along a line perpendicular to the plane of the paper at the point *d*. This is the *contact line* but it is usually referred to as the **contact point,** because only the point *d* appears on the paper. Now, if the gears are to run smoothly, the line *e f* drawn through the contact point *d* perpendicular to the tooth outline at that point, must pass through the point *g* in which the line of centers crosses the pitch circles. Therefore, any curve so shaped that the perpendicular to the tooth curve through the point of contact always passes through the point *g* is suitable for use as a tooth curve.

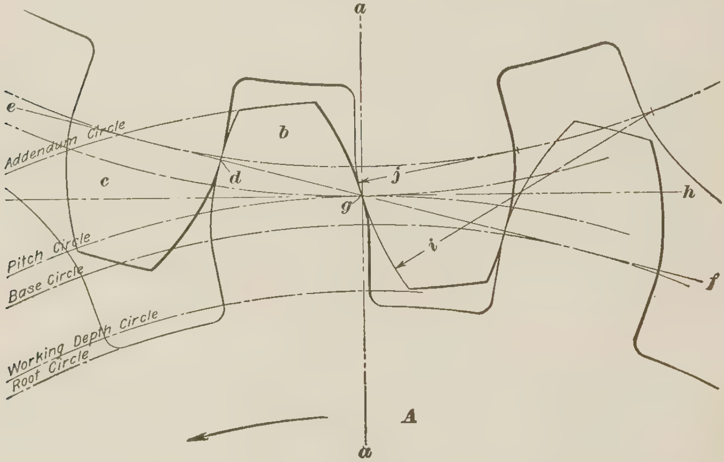

FIG. 4

There are a number of curves that might be used for tooth outlines, but, for practical reasons, it is customary to use one or the other of two curves. The curve most commonly used is called an involute, and gears having this form of tooth outline are called **involute gears.** The other form of tooth curve is the cycloid. Gears in which the cycloid is used for the tooth outline are called **cycloidal gears.** The laying out of either of these curves accurately is rather a complicated process. In practice it is therefore customary to lay out gear-tooth outlines by some approximate method in which the tooth curves are circular arcs. The following methods have been found sufficiently accurate for most practical purposes:

24. Laying Out of Involute Tooth Curves.—In order to lay out the involute tooth curve it is first necessary to draw the base circle on which the centers of the tooth arcs are located. The base circle is shown in Fig. 4, just inside of the pitch circle. The diameter of the base circle is found in the following manner: Draw the line $g\,h$ through the point g and at right angles to the line of centers $a\,a$. Then draw the line $e\,g\,f$; this is known as the **line of action,** because the pressure between the teeth always acts along this line, and the base circle tangent to it. The diameter of the base circle will vary with the angle $f\,g\,h$, which is called the **angle of obliquity,** and the shape of the involute will also be affected. For the purposes of gearing, a value of 15 degrees has been assumed for the angle $f\,g\,h$, and the resulting involute is therefore called the **15-degree involute.** For practical reasons, however, standard gear cutters are usually made with an angle a trifle less than 14½ degrees instead of 15 degrees. Gears are sometimes made with a 20-degree involute for the tooth outline, but these will be explained in a later article; the present description applies only to the standard involute tooth outline.

The diameter of the base circle may be found without drawing the angle $f\,g\,h$ by the use of the following rules:

Rule I.—*To find the diameter of the base circle for a 15-degree involute when the diameter of the pitch circle is known, multiply the diameter of the pitch circle by .966.*

Rule II.—*To find the diameter of the base circle for a 14½ degree involute when the diameter of the pitch circle is known, multiply the diameter of the pitch circle by .968.*

The involute curve of the gear-tooth may be very closely approximated by the use of one or more circular arcs. Table III gives radii for these circular arcs, and is known as an odontograph table.

TABLE III

INVOLUTE ODONTOGRAPH TABLE

No. of Teeth	Divide by the Diametral Pitch		Multiply by the Circular Pitch	
	Face Radius	Flank Radius	Face Radius	Flank Radius
10	2.28	.69	.73	.22
11	2.40	.83	.76	.27
12	2.51	.96	.80	.31
13	2.62	1.09	.83	.34
14	2.72	1.22	.87	.39
15	2.82	1.34	.90	.43
16	2.92	1.46	.93	.47
17	3.02	1.58	.96	.50
18	3.12	1.69	.99	.54
19	3.22	1.79	1.03	.57
20	3.32	1.89	1.06	.60
21	3.41	1.98	1.09	.63
22	3.49	2.06	1.11	.66
23	3.57	2.15	1.13	.69
24	3.64	2.24	1.16	.71
25	3.71	2.33	1.18	.74
26	3.78	2.42	1.20	.77
27	3.85	2.50	1.23	.80
28	3.92	2.59	1.25	.82
29	3.99	2.67	1.27	.85
30	4.06	2.76	1.29	.88
31	4.13	2.85	1.31	.91
32	4.20	2.93	1.34	.93
33	4.27	3.01	1.36	.96
34	4.33	3.09	1.38	.99
35	4.39	3.16	1.39	1.01
36	4.45	3.23	1.41	1.03
37–40	4.20		1.34	
41–45	4.63		1.48	
46–51	5.06		1.61	
52–60	5.74		1.83	
61–70	6.52		2.07	
71–90	7.72		2.46	
91–120	9.78		3.11	
121–180	13.38		4.26	
181–360	21.62		6.88	

25. The Involute Odontograph Table.—By the involute odontograph method, for all gears having fewer than 37 teeth, the curve is approximated by two circular arcs—one extending from the pitch circle to the addendum circle and the other from the pitch circle to the base circle—having different radii, the center of the arc for each being on the base circle.

The lengths of the radii with which the two arcs are drawn are obtained by the following method: In Table III, which is taken from Grant's "Treatise on Gear-Wheels," are two sets of numbers, a part of each set being in two columns. The first set has the general heading Divide by the Diametral Pitch and the two columns in this set have the respective headings Face Radius and Flank Radius. This set is to be used with the diametral-pitch system. To find the radius i, Fig. 4, for the face of a tooth for a gear having fewer than 37 teeth, divide the number in the column headed Face Radius, opposite the number that corresponds with the number of teeth in the gear, by the diametral pitch. To find the radius j of curved part of the flank, divide the corresponding number in the column headed Flank Radius by the diametral pitch.

The second set of two columns of numbers is headed Multiply by the Circular Pitch and is to be used with the circular-pitch system. It is used in the same manner as the first set, except that the numbers taken from the table are to be *multiplied* by the circular pitch.

Applying this method to the diametral-pitch gear of Fig. 4, in which the number of teeth is 18 and the pitch 2, proceed as follows: To find the radius of the face, look in the first column for the number 18 and in the same horizontal line in the column headed Face Radius, find the number 3.12, which, divided by the diametral pitch, gives $3.12 \div 2 = 1.56$ inches as the radius i of the face. In the same horizontal line and in the column headed Flank Radius, find the number 1.69; this number divided by 2 gives $1.69 \div 2 = .85$ inch, nearly, as the radius j of the flank.

26. Odontograph Table for Gears Having More Than 36 Teeth.—An inspection of Table III shows that for gears having more than 36 teeth there is but one column of figures under each of the respective headings of diametral pitch and circular pitch. The reason is that the whole curve is drawn with a single radius, whose length is determined by the general method already explained. It is constant for all gears the numbers of whose teeth are included in the several pairs of numbers given in the column headed No. of Teeth; for instance, the length of the radius for all numbers of teeth from 37 to 40 is determined by the use of the numbers in the horizontal line in which these numbers occur.

Example.—What is the length of the radius for the curves of the teeth of a gear having 64 teeth, 1.473 inches circular pitch?

Solution.—Since the number of teeth lies between the numbers 61–70 in the first column of the table, and the pitch is in the circular-pitch system, multiply 2.07, which is found in the second set of figures at the right of the numbers 61–70 and in the same horizontal row by the pitch. Performing the multiplication gives $2.07 \times 1.473 = 3.049$, say 3 in., as the length of the radius. Ans.

27. **Completing the Tooth Outline.**—With the foregoing method of constructing the tooth outline, the flanks of the teeth are radial between the base circle and the working-depth circle; this part of the outline is therefore made to coincide with the straight line from the center of the pitch circle to the point where the curved portion of the outline intersects the base circle, as shown in Fig. 4. A fillet from the working-depth circle connects the radial portion of the outline with the root circle and completes the outline of the tooth. The radius of this fillet is generally made equal to one-tenth the thickness of a tooth at the pitch circle.

28. **Minimum Number of Teeth.**—When a gear-tooth is narrower at the root than at the pitch circle it is said to be **undercut.** The flanks of involute teeth are always drawn radial inside of the base circle and involute teeth are therefore usually undercut. Under certain conditions the width of the tooth at the base circle may be enough larger than that at the pitch circle to make up for the undercutting due to the radial flanks inside of the base circle, and the thickness

of the tooth at the root may therefore be nearly equal to that at the pitch circle. When a gear has a very small number of teeth, the flanks are undercut so far that the strength is seriously affected. It is, therefore, not usually wise to use gears having a very small number of teeth. By using Table III, in the manner explained, it is possible to make satisfactory gears having as few as ten teeth.

When the single-arc method of approximating the tooth outline is being used, the gear should have at least 30 teeth. With a smaller number of teeth the difference between the correct tooth curve and the approximate curve is so great that the resulting gear will not work satisfactorily.

29. Involute Rack Teeth.—A *rack* is a gear in which the pitch radius is so long that the pitch circle has become a straight line and is called a *pitch line*. The diametral pitch of a rack is the same as the diametral pitch of any gear that will mesh with it and may be found by dividing 3.1416 by the circular pitch.

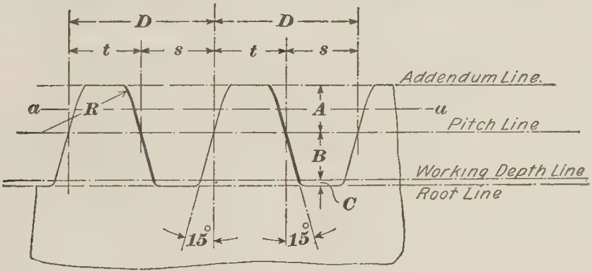

FIG. 5

30. The teeth of a rack that is to mesh with an involute gear of a given pitch may be laid out by the following method, which is known as "Grant's rule for rack teeth": First draw the addendum, pitch, and root lines, Fig. 5, making the distances *A* and *B* each equal to 1 divided by the diametral pitch, and the distance *C* equal to $t \div 10$. On the pitch line lay off the pitch distances *D*, *D*, and divide them into the two parts *t* and *s*, corresponding, respectively, to the thickness of the teeth and the width of the spaces on the pitch line. Draw the sides of the teeth from the working-depth line to the line *a a*, which is drawn half way between the pitch line and the addendum line, as straight lines making angles of 15° with lines that pass through the pitch points perpendicular to the pitch line. Draw the outer half of the face as a circular arc having a radius *R* whose length is 2.1 divided by the diametral pitch, or .67 multiplied by the circular pitch. A fillet from the working-depth line to the root line completes the outline of each side of the tooth.

31. Laying Out of Cycloidal-Tooth Curves.—A practical method of approximating the shape of the cycloidal-tooth curve by means of circular arcs was also devised by Mr. George B. Grant. The lengths of the radii of the arcs and the location of their centers are determined by the pitch and the number of teeth of the gear, in conjunction with a table of factors that apply to gears of all sizes from a 10-tooth pinion to a rack. Any two gears with teeth of the same pitch and height laid out by this method will work satisfactorily with each other.

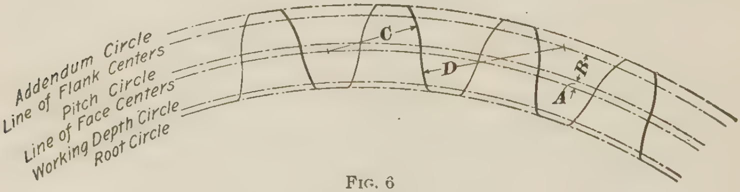

FIG. 6

32. Use of Cycloidal Odontograph Table.—The first step in the use of the odontograph table is the location of the circles on which lie the centers of the arcs, Fig. 6. These circles have the same center as the pitch circle, and their distances from it are determined in the following manner: In Table IV, which is taken from Grant's "Treatise on Gear-Wheels," are three sets of numbers, headed, respectively, No. of Teeth, Divide by the Diametral Pitch, and Multiply by the Circular Pitch. To find the distance *A* from the pitch circle at which to draw the line of face centers for a diametral-pitch gear with a given number of teeth, use the numbers in the

TABLE IV

CYCLOIDAL ODONTOGRAPH TABLE

No. of Teeth	Divide by the Diametral Pitch				Multiply by the Circular Pitch			
	Faces		Flanks		Faces		Flanks	
	Rad. *C*	Dis. *A*	Rad. *D*	Dis. *B*	Rad. *C*	Dis. *A*	Rad. *D*	Dis. *B*
10	1.99	.02	−8.00	4.00	.62	.01	−2.55	1.27
11	2.00	.04	−11.05	6.50	.63	.01	−3.34	2.07
12	2.01	.06	∞	∞	.64	.02	∞	∞
13–14	2.04	.07	15.10	9.43	.65	.02	4.80	3.00
15–16	2.10	.09	7.86	3.46	.67	.03	2.50	1.10
17–18	2.14	.11	6.13	2.20	.68	.04	1.95	.70
19–21	2.20	.13	5.12	1.57	.70	.04	1.63	.50
22–24	2.26	.15	4.50	1.13	.72	.05	1.43	.36
25–29	2.33	.16	4.10	.96	.74	.05	1.30	.29
30–36	2.40	.19	3.80	.72	.76	.06	1.20	.23
37–48	2.48	.22	3.52	.63	.79	.07	1.12	.20
49–72	2.60	.25	3.33	.54	.83	.08	1.06	.17
73–144	2.83	.28	3.14	.44	.90	.09	1.00	.14
145–300	2.92	.31	3.00	.38	.93	.10	.95	.12
301 to rack	2.96	.34	2.96	.34	.94	.11	.94	.11

column headed Divide by the Diametral Pitch. Select from the column headed Dis. A, under the heading Faces, the number in the same horizontal line as the number corresponding to the number of teeth in the gear. This number divided by the diametral pitch gives the distance in inches from the pitch circle to the circle of face centers. The distance B from the pitch circle to the circle of flank centers is found by dividing the number in the column headed Dis. B, under the heading Flanks, corresponding to the number of teeth in the gear, by the diametral pitch.

The lengths of the radii C and D of the arcs forming the outlines of the faces and flanks of the teeth are found by dividing the numbers in the respective columns headed Rad. C and Rad. D, corresponding to the number of teeth, by the diametral pitch.

For a circular-pitch gear, the numbers headed Multiply by the Circular Pitch are to be used. The numbers are selected as in the diametral-pitch system, but the several distances and lengths of radii are found by multiplying the numbers in the table by the circular pitch.

33. Flanks for Cycloidal Gear-Teeth.—When the gear has more than 12 teeth the center of the arc forming the flank of the tooth will lie on the side of the arc away from the tooth, as shown in Fig. 6. When, however, the gear has 10 or 11 teeth the center of the arc forming the flank will lie on the side toward the tooth. This fact is indicated in Table IV by the placing of a minus sign (−) before the numbers for the radius D for gears having 10 and 11 teeth.

The flanks for gears having 12 teeth are *radial*. This fact is indicated in the table by the symbol for infinity (∞) in the columns for length of flank radius and distance from pitch circle to line of flank centers. To draw the flanks for these teeth draw a straight line from the pitch point toward the center of the pitch circle. Then draw a fillet from the point where this line touches the working-depth circle to the root circle.

34. Teeth of Internal Gears.—When the teeth of the gear are on the inside instead of the outside of the rim of the wheel, the gear is an **internal,** or **annular, gear.** The tooth of an annular gear is, however, the same shape as the space of a spur gear and the space of the annular gear is the same shape as the tooth of the spur gear. If the annular gear is made in the involute system the radial flanks are apt to interfere with the flanks of the pinion tooth; this is called **interference.** The tendency of the flanks of involute teeth to interfere is especially great when the difference between the number of teeth in the two wheels is small. The use of the cycloidal system of tooth curves eliminates this interference or reduces it to such an extent that only a slight correction is needed to remove it altogether. Some makers therefore prefer to use the cycloidal system of tooth curves for annular gears. In order to avoid interference when the cycloidal system of tooth curves is used, the annular gear must have at least 12 teeth more than the pinion that meshes with it.

BEVEL GEARS

GENERAL PRINCIPLES

35. Rolling Cones.—Motion may be transmitted from one shaft to another that is not parallel to it but whose center lines intersect, by the use of a pair of cones. These cones roll together and transmit motion by friction in the same manner as the pair of cylinders do in the case of parallel shafts. Gears in which the pitch surfaces are cones are **bevel gears.** A pair of equal gears connecting shafts at right angles are called **miter gears.**

36. Fig. 7 shows a pair of cones that would transmit motion from a shaft whose center line is at *A O* to one whose center line is at *B O*. Bevel gear-teeth are formed on one-half of each of these cones so that, if the teeth were continued all around the cones, the resulting bevel gears would transmit the same motion as the cones that form their pitch surfaces.

The pitch diameter of a bevel gear always means the diameter of the base of the pitch cone and the pitch circle is the circle that surrounds the base of the pitch cone. The pitch diameters of the gears in Fig. 7 are *a b* and *b c*, respectively, and the pitch circles are the circles having these diameters.

37. Convergence of Bevel-Gear Teeth.—In bevel gears the pitch cones have a common apex at the point of intersection of the center lines of the shafts connected by the gears, and the axes of the cones coincide with the center lines of these shafts. If the teeth of such gears are correctly formed, each tooth surface is made up of a series of straight lines, each of which, when produced, passes through the point of intersection of the center lines of the shaft, or the common apex of the two pitch cones; the teeth of a bevel gear may therefore be conceived as having been cut out by a straight line that always passes through the apex of the pitch cone while it is moved in contact with the outlines of the big ends of the teeth. For example, in Fig. 7, if we consider a straight line always passing through *O* while it is moved in contact with the outline *f g h i* of the big end of a correctly formed tooth, the line will coincide

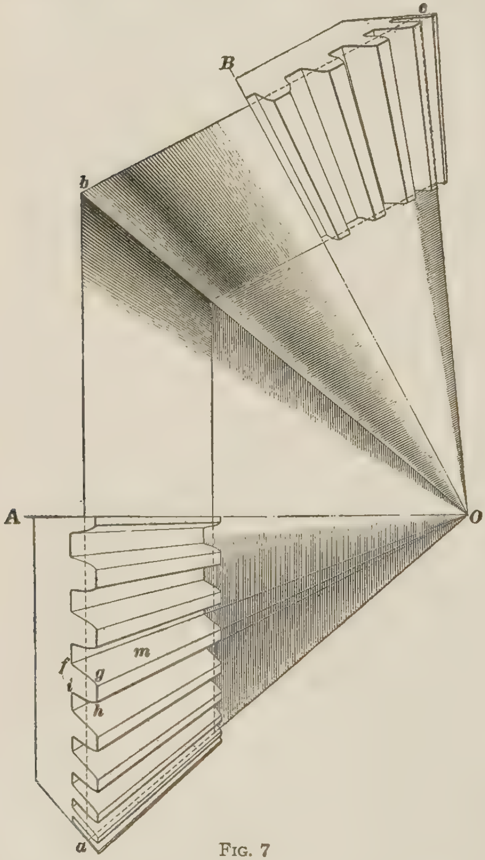

Fig. 7

with the surface *m* of the tooth for every point of its motion. On account of this convergence of the surfaces of the teeth, and the consequent change in the size of the tooth surface, it is impossible to correctly form either side of the teeth by passing either a formed planing tool or a milling cutter over it.

LAYING OUT BEVEL GEARS

38. Laying Out Pitch Cones When Shafts Are at Right Angles.—To lay out the pitch cones, first the center lines *o a* and *o b*, Fig. 8 (*a*), of the shafts are drawn at right angles to each other. The next step depends on the velocity, or on the relation between the diameters, or the numbers of teeth of the two gears, or their distance from the point of intersection of the center lines of the shafts.

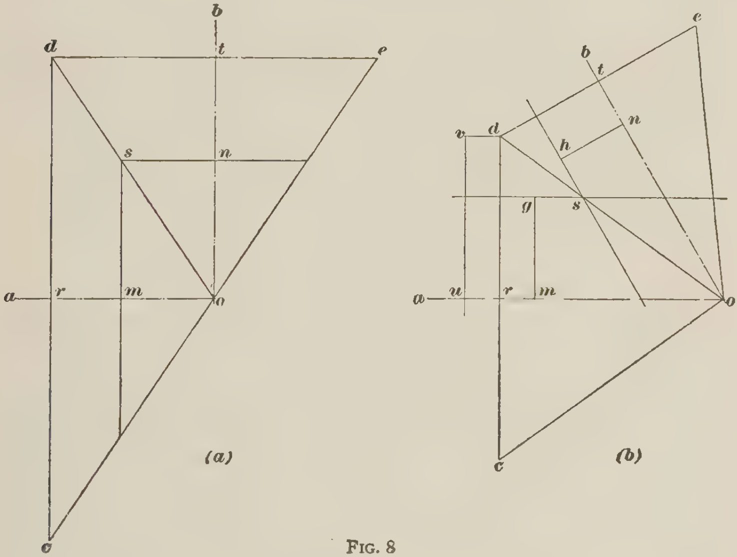

FIG. 8

When the shafts are at right angles to each other, and the diameters of the gears are given, or can be calculated, the points *r* and *t* are obtained by laying off from the point of intersection *o*, Fig. 8 (*a*), a distance on each line equal to the radius of the gear on the other shaft. Through the points *r* and *t* so obtained, the perpendiculars *c d* and *e d* are drawn intersecting in *d*. Then laying off *r c* and *t e* equal, respectively, to *r d* and *t d* and drawing the lines *o c*, *o d*, and *o e*, the outlines of the pitch cones *o c d* and *o d e* are completed. The angles *c o a* or *d o a*, and *e o b* or *d o b*, are called the **center angles** of their respective cones.

EXAMPLE.—Lay out the center angles of a pair of bevel gears for the shafts whose center lines are *o a* and *o b*, Fig. 8 (*a*). The gears are to have 48 and 32 teeth, respectively, and the angle between the center lines is 90°.

SOLUTION.—Since the sizes of the gears are proportional to the number of teeth in them, and the gear on the shaft *o a* is to have 48 teeth, while that on *o b* has 32, the distances to be laid off must be, respectively, 32 and 48 divisions on some convenient scale. Therefore, by laying off on *o a* a distance *o m* equal to 32 divisions and on *o b* a distance *o m* equal to 48 divisions, the points *m* and *n* are obtained through which the lines *m s* and *n s* can be drawn perpendicular, respectively, to the center lines *o a* and *o b*. By drawing the line *o s* through the point of intersection *s* of these perpendiculars and the point of intersection *o* of the center lines, the center angles *a o s* and *b o s* of the pitch cones are obtained. Ans.

39. Laying Out Pitch Cones When Shafts Are Not at Right Angles.—The center lines of the shafts are laid out, as *o a* and *o b*, Fig. 8 (*b*), at the given angle between the shafts, and any convenient distances, as *o m* and *o n*, are laid off on them. Through the points *m* and *n* so obtained lines are drawn perpendicular to the center lines of the shafts, as *m g* and *n h*, that are proportional either to the velocity of the gear on the other shaft or to the diameter or number of teeth of the gear on the shaft from whose center line the perpendicular is drawn. Then through the points *g* and *h* on these perpendiculars draw lines parallel to the center lines until they intersect each other. The line *o s* drawn through the point of intersection *s* of these parallels and the point of intersection *o* of the center lines of the shafts, fixes the center angles *d o a* and *d o b* of the gears.

40. When the distance from the point of intersection of the center lines to the base of one of the cones is given, the completion of the cones is accomplished by laying off the given distance, as *o r*, Fig 8 (*b*), on its proper center line. Through the point *r* draw the line *c d* perpendicular to *o a*, extending it until it intersects the line *o s* in *d*, and lay off *r c* equal to *r d*. Through *d* draw the line *d e* perpendicular to *o b* and make *t e* equal to *t d*. Draw *c o* and *e o*. The outlines of the two pitch cones are then *c o d* and *d o e*, respectively, and the pitch diameters of the two gears are *c d* and *d e*.

When the diameter of one or both of the gears is given, the pitch cones may be laid out by the other method illustrated in Fig. 8 (*b*). First, the contact line *o s* is laid out by the method explained; then, from any convenient point, as *u*, on the center line of the gear whose diameter is given, a perpendicular *u v* is drawn and on it the distance *u v* is laid off equal to the radius of the gear. Through *v*, a line *v d* is drawn parallel to *o a* until it intersects the contact line *o s* in *d*. The point *d* will be one extremity of the pitch lines of the gears. From *d*, the lines *d c* and *d e* are drawn perpendicular, respectively, to the axes *o a* and *o b*, making the distances *r c* and *t e* equal, respectively, to *r d* and *t d*; from the points *c* and *e* the lines *c o* and *e o* are drawn. The outlines of the pitch cones are *c o d* and *d o e*.

41. Laying Out Bevel-Gear Blanks.—The method of laying out the blanks for a pair of bevel gears is illustrated in Fig. 9. Before the diameters of the blanks and the depth of the cut can be found, however, it is necessary to lay out the pitch cones in the manner explained in Art. **38** or that explained in Art. **39.** The pitch cones in these gears are *O a b* and *O b c*, and the pitch diameters of the gears are *a b* and *b c*, respectively. The size and shape of the bevel-gear teeth at the big end are the same as would be used on a spur gear whose pitch radius may be found as follows: Draw a line through the point *b* perpendicular to the line *b O* and continue it until it intersects the center lines of the gears at *M* and *N*, respectively. The cone of which *N b* is one side, and *b c* the base, is the *back cone*. With the point *N* as a center and *N b* as a radius draw the arc *b d*. This arc is a part of the *construction pitch circle* and is sometimes called the pitch line of the equivalent spur gear. The addendum, root, and depth of cut of the bevel gear are computed the same as for a spur gear having a pitch radius *N b*. The addendum is found by dividing the circular pitch of the bevel gear by 3.1416, and the root is found by multiplying the circular pitch of the bevel gear by .3683. The depth of the cut is, of course, the sum of the addendum and the root. By laying off the addendum and the root above and below the arc *b d* and drawing arcs about *N* through the points thus located, the points *e* and *f* are found. In a similar manner the points *g* and *h* may be located on the pinion. Then *h g* is the depth of the cut in the pinion and *e f* is the depth for the gear.

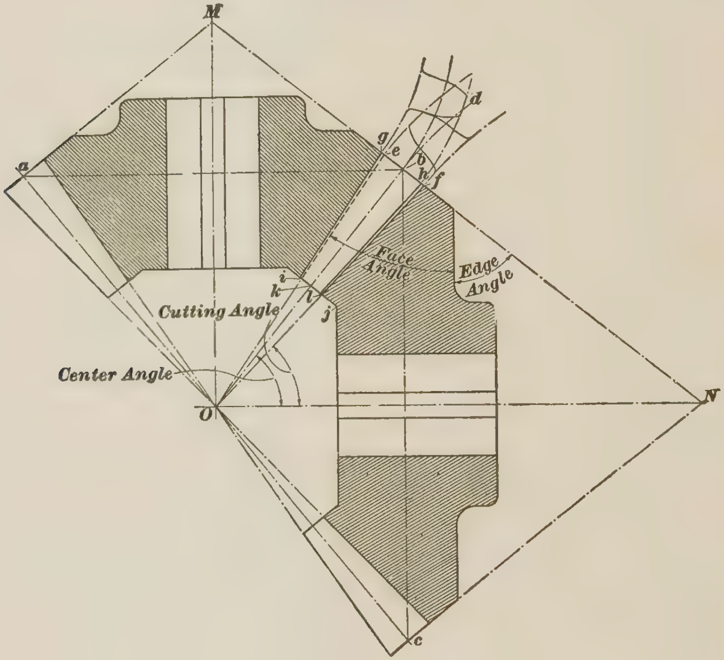

FIG. 9

42. Although the depth of the cut varies throughout the length of the tooth, it does not have to be calculated at any point except the large end. It is, however, necessary to find the values of some angles on the bevel gear in order to make the blank of the right size and shape and to enable the cutting to be done correctly. The size of some of these angles may be computed, but it is usually more convenient to make an accurate layout on paper and to measure these angles from the layout.

In order to find the *angle of the blank*, or the *face angle*, draw the line $i\ j$ perpendicular to the line $O\ b$ so that $k\ b$ equals the length of the tooth. Then draw the line $e\ i$ so that when produced it passes through O. The angle between the face $e\ i$ and any line perpendicular to the center line $O\ N$ is the face angle. The construction of the angle $N\ b\ c$ called the *edge angle*, has been explained in Art. **41.** This angle is the same size as the angle $b\ O\ N$, which is called the *center angle* or the *pitch angle*. The angle $f\ O\ N$ between the line forming the bottom of the cut and the center line $O\ N$ of the gear is the *cutting angle*. The diameter of the blank at the large end is measured from a layout, the diameter being taken over the points of the teeth at the large end of the gear.

WORMS AND WORM-WHEELS

KINDS OF WORMS

43. Description of Worm.—A **worm** is a screw whose threads mesh with a gear that is called a *worm-wheel*. The worm may have one, two, three, or more threads. The distance along the pitch line of the worm, from one tooth to the corresponding point on the next tooth, is the *pitch* of the worm. In a single-threaded worm the thread advances in each turn a distance equal to the pitch. In a double-threaded worm, however, the tooth advances a distance equal to twice the pitch in each turn and the second tooth is placed parallel to the first one and separated from it by a distance equal to the pitch. The advance of a tooth in one turn of the worm is called the *lead*. The lead of double- and triple-threaded worms is then, respectively, two and three times the pitch.

A single-threaded worm is shown in Fig. 10.

The axis of the worm is usually at right angles to that of the worm-wheel, and the *line of centers* of a worm and wheel is, therefore, the line through the center of the wheel and perpendicular to the center line of the worm.

If a worm were cut in two lengthwise, the tooth outline would be the same as for a rack to mesh with a gear having the same system of tooth curves as the worm-wheel. In the involute system, rack teeth, when uncorrected for interference, have straight sides, whereas, in the cycloidal system, rack teeth have curved sides. It is therefore easier to make the tool with which to cut the involute worm than the one with which to cut the cycloidal worm. Teeth of worms are therefore usually involutes.

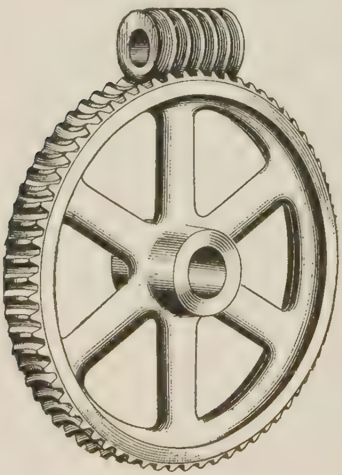

FIG. 10

44. Form of the Worm-Wheel.—A worm-wheel is a gear on which the teeth are cut in such a way that they will mesh with threads of the worm. Worm-wheels are usually of one of the three forms shown in Fig. 11. Fig. 11 (*a*) is a close-fitting wheel, because each tooth is curved so that it is in contact, throughout its whole length, with the tooth of the worm. In the wheel shown in Fig. 11 (*b*) the teeth are straight but they are at an angle such that the worm thread will mesh properly with them. The form of worm-wheel shown in Fig. 11 (*c*) is especially suited for locations in which the worm-wheel must occasionally be turned by hand. The first one of these wheels is cut by a tool called a hob, which is essentially a duplicate of the worm that is to mesh with the wheel. The other two worm-wheels are cut by means of milling cutters. In cutting the gear shown in Fig. 11 (*b*) the milling cutter is fed diagonally across the face of the wheel, and in the wheel shown in Fig. 11 (*c*) the cutter is fed in radially until the desired depth of cut has been obtained.

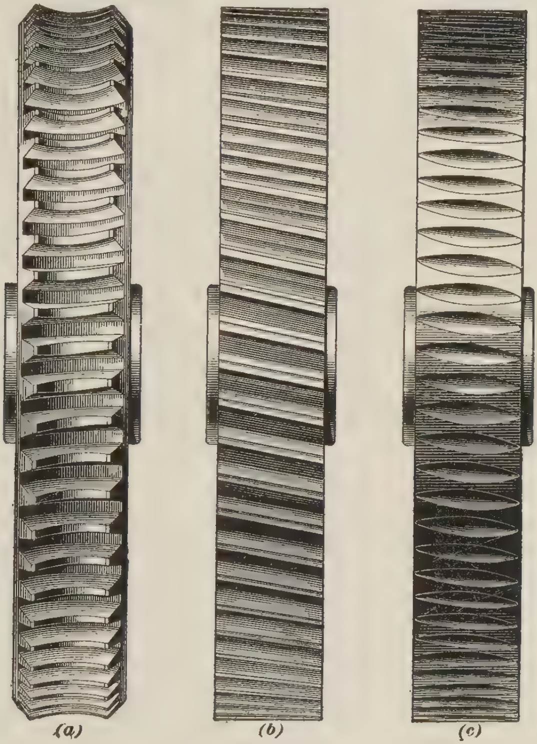

FIG. 11

WORM-WHEEL CALCULATIONS

45. Worm-Wheel Calculations in the Circular-Pitch System.—The various proportions of the worm-wheel may be calculated by means of the same rules that were given in Arts. **10** to **15** for use with spur gears, but the following differences should be carefully noted. In the close-fitting worm-wheel the pitch diameter *a b* is taken at the smallest point of the pitch surface, as will be seen by reference to Fig. 12. The throat diameter $c\,d$, also shown in Fig. 12, corresponds to the outside diameter, or the diameter of the spur-gear blank. There is, however, no dimension on a spur gear that corresponds to the blank diameter of a close-fitting worm-wheel, and this dimension, therefore, must be found by one of the two following methods:

First Method.—The blank diameter of a worm-wheel can usually be found with sufficient accuracy by making an accurate layout of the worm and worm-wheel and measuring the desired dimension from the drawing.

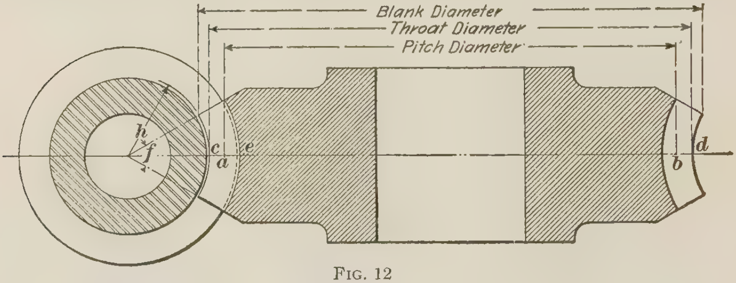

FIG. 12

Second Method.—The angle f, Fig. 12, is usually from 60° to 90° and the cos $\frac{f}{2}$ is therefore usually from .866 to .707. The exact value of cos $\frac{f}{2}$ may be obtained from a table of cosines, but it will frequently be accurate enough to use only three figures. When this is done, the third figure is made 1 larger than that given in the table when the fourth figure is 5 or more; when the fourth figure is less than 5, the third figure is the same as given in the table. The outside diameter of the worm-wheel may be found by applying the following rule:

Rule.—*To find the outside diameter of a worm-wheel when the throat diameter, the angle f, and the radius h of the face of the wheel are known, multiply 2 times h by 1 minus the cosine of $\frac{1}{2}$ of the angle f, and add the throat diameter.*

Example.—What is the outside diameter of a worm-wheel in which the throat diameter is 23 inches, the angle f is 70°, and the radius h of the face 1.7125 inches?

Solution.—The angle $\frac{f}{2}=\frac{70}{2}=35°$, and then by referring to a table of cosines it is found that $\cos 35°=.819$. Then, by applying the rule just given, the outside diameter of the worm-wheel is

$$2\times 1.7125\ (1-.819)+23=23.6199, \text{ or practically } 23.62 \text{ in. Ans.}$$

46. Worm-Wheel Calculations in the Diametral-Pitch System.—When some of the proportions of the worm-wheel are given, or are to be determined, in the diametral-pitch system, the calculations may be made in the manner explained in Arts. 16 to 21 for spur gears. In this connection it should, however, be remembered that the outside diameter of a spur gear corresponds to the throat diameter of a close-fitting worm-wheel and that the pitch diameter of a close-fitting worm-wheel is measured at the smallest part of the curved face. The method of finding the outside diameter of the worm-wheel will be the same as was explained in Art. 45.

47. Worm-Wheels With Less Than 30 Teeth.—When the tooth curves are 15° involutes and the worm-wheel has less than 30 teeth, the teeth on the worm-wheel will be undercut, a condition usually considered undesirable. This undercutting may be avoided in at least two ways, but as the first of these methods involves the making of special cutters, which the other method does not require, the second method is to be preferred. In this method the throat diameter is made somewhat larger than would be given by the rules of Art. 12. In order to avoid undercutting, the throat diameter may be calculated by the following rule:

Rule.—*To find the throat diameter that will avoid undercutting the teeth of a worm-wheel, multiply the number of teeth divided by the diametral pitch by .937 and add 4 times the addendum.*

Example.—What should be the throat diameter to prevent undercutting in the teeth of a worm-wheel having 18 teeth of 4 diametral pitch and in which the addendum is $\frac{1}{4}$ inch?

Solution.—Applying the rule just given, the throat diameter is

$$(18\div 4)\times .937+4\times\tfrac{1}{4}=5.216, \text{ or practically } 5.22 \text{ in. Ans.}$$

WORM CALCULATIONS

48. Pitch Diameter of Worm.—The velocities of a worm and worm-wheel are independent of the relative pitch diameters of the worm-wheel and worm, from which fact it follows that in designing a worm and worm-wheel for a given distance between centers, there is a choice of many different proportions. When the pitch diameter of the worm-wheel and the distance between centers are known, the pitch diameter of the worm may be found by means of the following rule:

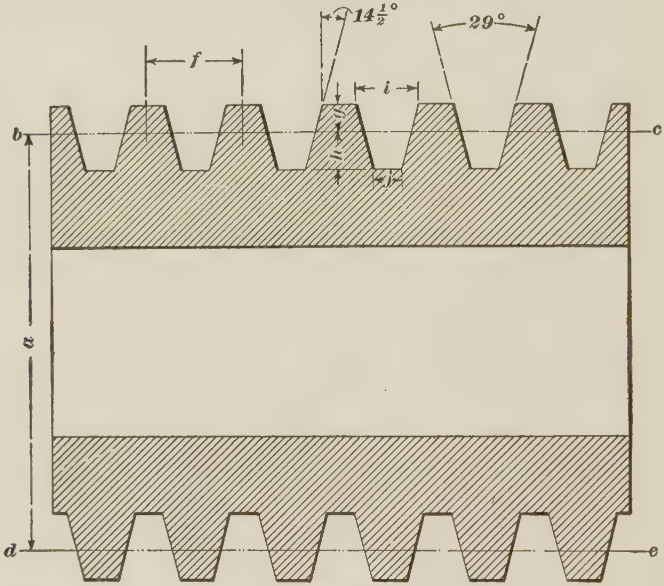

FIG. 13

Rule.—*To find the pitch diameter of the worm when the pitch diameter of the worm-wheel and the distance between centers are known, subtract half the pitch diameter of the worm-wheel from the distance between centers and double the remainder.*

49. Outside Diameter of Worm.—The pitch diameter *a* of the worm, as represented by the lines *b c* and *d e*, Fig. 13, should always be computed as stated in Art. **48.**

When the worm-wheel has 30 or more teeth, calculate the outside diameter by the following rule:

Rule.—*To find the outside, or blank, diameter of the worm when the pitch diameter of the worm and the circular pitch f, Fig. 13, of the worm-wheel are known, multiply the circular pitch of the worm-wheel by .6366 and add the pitch diameter of the worm.*

Example.—A triple-threaded worm is to have a pitch diameter of 3 inches and a lead of 1.5 inches. What should be the diameter of the blank for the worm?

Solution.—Since the worm is triple-threaded, the distance f, according to Art. **43**, is $1.5 \div 3 = .5$ in. Applying the rule just given, the diameter of the worm blank is

$$.5 \times .6366 + 3 = 3.318 \text{ in. Ans.}$$

50. Proportions of Worm Thread.—The addendum and flank of the worm thread are the same as those of the worm-wheel and may therefore be calculated by the rules given in Art. **10.**

The angle between the face of a worm-tooth and a line perpendicular to the axis of the worm is the same as the angle of obliquity of the teeth on the wheel that mates with the worm. The angle of worm threads is commonly 14½°, so that the angle between the sides of a worm-tooth is 29°, as shown in Fig. 13. The width j at the bottom of the cut in such a thread may then be found by means of the following rule:

Rule.—*To find the width of the space at the bottom of the cut when the circular pitch of the worm-wheel is known, multiply the circular pitch by .31.*

Example.—What should be the width of the space at the bottom of the cut in a worm to mesh with a worm-wheel having a circular pitch of .5 inch?

Solution.—Applying the rule, the width of the space is

$$.5 \times .31 = .155 \text{ in. Ans.}$$

51. Length of Worm.—The length of the worm can best be determined by making a layout of the worm and worm-wheel, the worm being proportioned so that the end threads are not in contact with the teeth of the worm-wheel. Any greater length of worm is useless, and any length less than this will reduce the number of teeth in contact and consequently the strength of the worm and worm-wheel.

52. Angle of Worm Thread.—The angle between the surface of the thread of a worm and a line at right angles to the axis of the worm is the angle of the worm thread. The tangent of this angle may be found by dividing the lead of the worm thread by 3.1416 times the pitch diameter of the worm. By referring to a table of tangents, the angle found to correspond to this tangent is the angle of the worm thread.

SPIRAL GEARS

53. To Find the Normal Pitch.—*Spiral gears* are gears in which the teeth are not at right angles to the face of the gear. The teeth are, therefore, portions of spirals, or helixes, for which reason the gears are sometimes called *helical gears*. The angle of the teeth is the angle *m*, Fig. 14, between a tooth and the line *A D* parallel to the axis of the gear. The circular pitch of a spiral gear is measured parallel to the face of the gear. In Fig. 14, the teeth are represented by lines supposed to be drawn on the pitch cylinder. The circular pitch is shown at *A B*. Most spiral gear calculations are, however, made with the *normal circular pitch A C*, which is measured at right angles to the face of the tooth. The normal circular pitch may be found by means of the following rule:

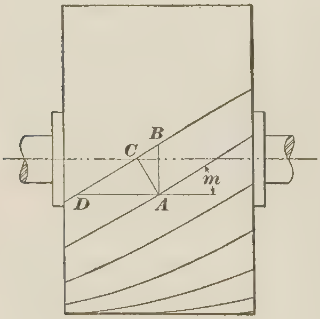

FIG. 14

Rule.—*To find the normal circular pitch of a spiral gear when the circular pitch and the angle of the teeth are known, multiply the circular pitch by the cosine of the angle of the teeth.*

Example.—What is the normal circular pitch of a spiral gear in which the circular pitch is 1.047 inches and the tooth angle is 30°?

Solution.—By referring to a table of cosines it is found that cos 30° =.866. Then, applying the rule just given, the normal circular pitch is

$$1.047 \times .866 = .9067 \text{ in. Ans.}$$

The *normal diametral pitch* is the diametral pitch corresponding to the normal circular pitch. The normal diametral pitch may be found by applying rule I of Art. **9**, which, for the normal diametral pitch, becomes 3.1416 divided by the normal circular pitch.

54. To Find the Pitch Diameter.—The pitch diameter of a spiral gear may be found by the use of the following rules:

Rule I.—*To find the pitch diameter of a spiral gear when the circular pitch and the number of teeth are known, multiply the product of the circular pitch and the number of teeth by .3183.*

Example 1.—What is the pitch diameter of a spiral gear having 30 teeth and a circular pitch of 1.047 inches?

Solution.—Applying the rule just given, the pitch diameter is

$$1.047 \times 30 \times .3183 = 9.9978, \text{ or practically 10 in. Ans.}$$

Rule II.—*To find the pitch diameter of a spiral gear when the normal circular pitch, the number of teeth, and the angle of the teeth are known, multiply the product of the normal circular pitch and the number of teeth by .3183 and divide by the cosine of the angle of the teeth.*

Example 2.—What is the pitch diameter of a spiral gear having 30 teeth, a normal circular pitch of .9067 inch, and a tooth angle of 30°?

Solution.—By referring to a table of cosines it is found that cos 30° =.866. Then, applying the rule just given, the pitch diameter is

$$.9067 \times 30 \times .3183 \div .866 = 9.9977, \text{ or 10 in. Ans.}$$

Rule III.—*To find the pitch diameter of a spiral gear when the normal diametral pitch, the number of teeth, and the tooth angle are known, divide the number of teeth by the product of the normal diametral pitch and the cosine of the tooth angle.*

Example 3.—What is the pitch diameter of an 8-pitch spiral gear having 40 teeth and a tooth angle of 35°?

Solution.—By referring to a table of cosines it is found that cos 35° =.819. Then, applying the rule just given, the pitch diameter is

$$40 \div (8 \times .819) = 6.105 \text{ in.} \quad \text{Ans.}$$

55. To Find the Diameter of Spiral-Gear Blank. The diameter of the blank for a spiral gear may be found by means of the following rule:

Rule.—*To find the diameter of a spiral-gear blank when the pitch diameter and the normal circular pitch are known, add .6366 times the normal circular pitch to the pitch diameter.*

Example.—What is the diameter of the blank for a spiral gear having a pitch diameter of 10 inches and a normal circular pitch of .9067 inch?

Solution.—Applying the rule just given, the diameter of the blank is

$$10 + .6366 \times .9067 = 10.577 \text{ in.} \quad \text{Ans.}$$

56. Miscellaneous Spiral-Gear Rules.—The angle at which to cut the teeth of a spiral gear will be found in a table of cosines corresponding to the cosine obtained by applying the following rule:

Rule I.—*To find the cosine of the angle at which to cut the teeth of a spiral gear for which the number of teeth, the normal diametral pitch, and the pitch diameter are known, divide the number of teeth by the product of the normal diametral pitch multiplied by the pitch diameter.*

Example 1.—What is the angle of the teeth on a spiral gear having 40 teeth, 8 diametral pitch, and 6 inches pitch diameter?

Solution.—Applying the rule just given, the cosine of the tooth angle is

$$40 \div (8 \times 6) = .8333$$

This corresponds very nearly with the cosine 33° and 34′. Therefore, the tooth angle is 33° 34′. Ans.

Rule II.—*To find the normal diametral pitch of a spiral gear when the outside diameter, the number of teeth, and the angle of the teeth are known, divide the number of teeth by the cosine of the tooth angle, add 2, and divide by the outside diameter.*

Example 2.—What is the normal diametral pitch of a spiral gear having an outside diameter of 6.353 inches and 40 teeth making an angle of 35° with the axis?

Solution.—The cos of 35° is .819, and applying the rule just given, the diametral pitch is

$$(40 \div .819 + 2) \div 6.353 = 8. \quad \text{Ans.}$$

57. The lead of a spiral may be found by applying the following rule:

Rule.—*To find the lead of a spiral when the number of teeth, the circular pitch, and the angle of the teeth are known, divide the number of teeth multiplied by the circular pitch by the tangent of the tooth angle.*

Example.—What is the lead of the spiral of a gear having 40 teeth, a circular pitch of .322 inch, and a tooth angle of 35°?

Solution.—The tangent of 35° is .7, and applying the rule just given, the lead is

$$40 \times .322 \div .7 = 18.4 \text{ in.} \quad \text{Ans.}$$

GEAR CUTTING

PRINCIPLES OF GEAR CUTTING

SPUR-GEAR CUTTING

GENERAL PRINCIPLES

1. Types of Gears and Gear-Cutting Machines. There are four types of gears commonly cut in machine-shop practice; they are, *spur gears*, including racks and internal, or annular, gears; *helical gears; bevel gears;* and *worm-gears*. When any of these gears are to be cut in large quantities, suitable gear-cutting machines should be used. Gear-cutting machines either mill or plane the teeth. In gear-milling machines, the cutter rotates while cutting the gear and in gear-planing machines, sometimes called *gear-shapers*, the cutter moves back and forth in a straight path. In each of these two types of gear-cutting machines, the gear may or may not rotate while it is being cut. In order to make very accurate hardened gears, grinding is necessary after they have been cut and hardened, to correct any distortion from the hardening process.

2. Shapes of Gear-Cutters.—Milling cutters for spur gears usually have the same shape as the tooth space. The tools used for planing gears may have the shape of the space between two teeth, but it is more common practice to give the planing tool the same shape as that of the tooth of a gear

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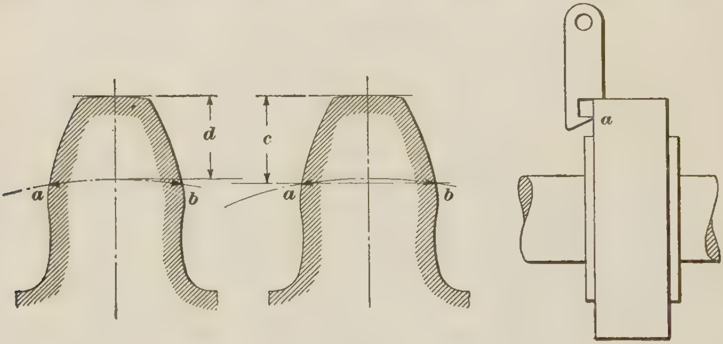
with which the one being cut will mesh. When the tool moves back and forth, it traces the outline of a tooth on the gear with which the one being cut is to mesh. If the gear-blank is moved past the planing tool in the same manner that it will move relative to a tooth of the mating gear, a space of the correct shape will be cut. Teeth cut in this way are *generated*. When teeth are generated, the tool will always cut a tooth that will work properly with teeth having the same shape as the tool. If the shape of the tool is that of an involute tooth, the teeth cut will have correct involute outlines; and if the shape of the tool is that of a cycloidal tooth, the generated tooth will have a correct cycloidal outline.



(a) (b) (c)

FIG. 1

A tool having any other shape than that of an involute or a cycloidal tooth, will cut a tooth that is commonly called a *conjugate tooth;* that is, one that will work properly with a tooth having the same shape as the tool.

3. Chordal Tooth Thickness, Corrected Addendum, and Depth Gauge.—The thickness of a gear-tooth, unless otherwise stated, always means the length of the arc *a b*, Fig. 1 (*a*), of the pitch circle. When measuring the tooth thickness with a pair of gear-calipers, it is impossible to measure this length. The length of the chord *a b*, Fig. 1 (*b*), can, however, be measured when the height *c* is known. The chord *a b* is the **chordal thickness** of the tooth, and the height c is the **corrected addendum**; the height d is the real addendum. Table I, from the Brown & Sharpe Manufacturing Company, gives the chordal thickness and corrected addendum of gears of 1 diametral pitch. When finding the corrected addendum or chordal thickness for the teeth of a gear whose number of teeth is not given in this table, the nearest number of teeth that is given may be used.

TABLE I

CHORDAL THICKNESS AND CORRECTED ADDENDUM FOR 1 DIAMETRAL PITCH

Number of Teeth	Chordal Tooth Thickness	Corrected Addendum	Number of Teeth	Chordal Tooth Thickness	Corrected Addendum
8	1.5607	1.0768	21	1.5694	1.0294
9	1.5628	1.0684	23	1.5696	1.0268
10	1.5643	1.0616	26	1.5698	1.0237
11	1.5654	1.0559	30	1.5701	1.0208
12	1.5663	1.0514	35	1.5702	1.0176
13	1.5670	1.0474	42	1.5704	1.0147
14	1.5675	1.0440	55	1.5706	1.0112
15	1.5679	1.0411	80	1.5707	1.0077
17	1.5686	1.0362	135	1.5708	1.0046
19	1.5690	1.0324			

To find the corrected addendum of any other than a 1 diametral pitch gear, the following rule should be applied:

Rule.—*To find the chordal tooth thickness and corrected addendum of a gear that is not 1 diametral pitch, the chordal thickness and corrected addendum for a gear having the same number of teeth of 1 diametral pitch must be divided by the diametral pitch of the given gear.*

EXAMPLE.—What is the chordal thickness and the corrected addendum of the teeth of a 10 diametral pitch gear having 32 teeth?

SOLUTION.—The chordal tooth thickness of a 1 diametral pitch gear having 32 teeth is found from Table I to be 1.5701 in. Then, by applying the rule, the chordal thickness of the gear-teeth that are to be measured is found to be

$$1.5701 \div 10 = .157 \text{ in.} \quad \text{Ans.}$$

In a like manner, the corrected addendum is found to be

$$1.0208 \div 10 = .102 \text{ in.} \quad \text{Ans.}$$

4. The chordal thickness and corrected addendum of 1 diametral pitch gears, as given in Table I, may be found by the following rules:

Rule I.—*To find the chordal tooth thickness of a 1 diametral pitch gear when the number of teeth is known, divide 90° by this number, find the sine of the angle thus obtained, and multiply by the number of teeth.*

Rule II.—*To find the corrected addendum of a 1 diametral pitch gear when the number of teeth is known, divide 90° by this number, subtract the cosine of the angle thus obtained from 1, multiply by half the number of teeth, and add 1.*

The chordal tooth thickness and the corrected addendum for a gear having any other than 1 diametral pitch may then be found by applying the rule of Art. **3**.

5. When the gear is to be measured according to the circular-pitch system, the chordal thickness and corrected addendum for a gear of 1-inch circular pitch may be taken from Table II. The values given in Table II, furnished by the Brown & Sharpe Manufacturing Company, may be corrected for other pitches by applying the following rule:

Rule.—*To find the chordal tooth thickness and the corrected addendum of a gear that is not 1-inch circular pitch, the chordal thickness and corrected addendum for a gear having the same number of teeth of 1-inch circular pitch must be multiplied by the circular pitch of the gear to be measured.*

Example.—What are the chordal thickness and the corrected addendum of the teeth of a gear having 15 teeth of .5-inch circular pitch?

Solution.—By referring to Table II and applying the rule, the chordal thickness is found to be

$$.4991 \times .5 = .24955, \text{ or practically } .25, \text{ in.} \quad \text{Ans.}$$

The corrected addendum is

$$.3314 \times .5 = .1657, \text{ or practically } .166, \text{ in.} \quad \text{Ans.}$$

6. The chordal thickness and corrected addendum of 1-inch circular-pitch gears, as given in Table II, may be found by the following rules:

Rule I.—*To find the chordal tooth thickness of a 1-inch circular pitch gear when the number of teeth is known, find the sine of 90° divided by the number of teeth and multiply it by the number of teeth and by .3183.*

Rule II.—*To find the corrected addendum of a 1-inch circular pitch gear when the number of teeth is known, find the cosine of 90° divided by the number of teeth and subtract it from 1. Then multiply the result just obtained by half the number of teeth, add 1, and multiply by .3183.*

The chordal tooth thickness and the corrected addendum may be found for a gear of any other than 1-inch pitch by multiplying the chordal thickness or the corrected addendum for 1-inch circular pitch by the circular pitch of the gear to be measured.

TABLE II

CHORDAL THICKNESS AND CORRECTED ADDENDUM FOR 1-INCH CIRCULAR PITCH

Number of Teeth	Chordal Tooth Thickness	Corrected Addendum	Number of Teeth	Chordal Tooth Thickness	Corrected Addendum
8	.4968	.3428	21	.4996	.3277
9	.4975	.3401	23	.4997	.3268
10	.4979	.3379	26	.4997	.3258
11	.4983	.3361	30	.4998	.3249
12	.4986	.3347	35	.4998	.3239
13	.4988	.3334	42	.4999	.3230
14	.4990	.3323	55	.5000	.3219
15	.4991	.3314	80	.5000	.3208
17	.4993	.3298	135	.5000	.3198
19	.4995	.3286			

When the blank has been turned to the correct size, a **gear-tooth-depth gauge** may be used for marking the correct depth of cut on the blank. Such a gauge is shown in Fig. 1 (*c*). It has at one end a rectangular slot, the width of which is made equal to the depth of cut for the diametral pitch for which gauge is intended. The point *a* is hardened and is used for scribing a line representing the correct depth of tooth on the blanks by applying the gauge as shown in the illustration and observing the precaution of holding it radially during the scribing. The cutter is then sunk into the blank to the depth indicated by the scribed line.

MILLING PROCESS

7. Gear-Milling Machines.—Gear milling may be done on an ordinary milling machine that is provided with a suitable indexing attachment. The rim of the blank must be supported against the thrust of the cutter when the arbor on which the gear is mounted does not hold the gear sufficiently rigid. The fixtures illustrated in Figs. 2 and 3 may each be used on an ordinary milling machine for the production of spur gears, each within its own range. Fig. 2 shows an indexing attachment for use on a milling machine, in which the gear being cut is held vertically. The head-stock and the foot-stock are to be bolted to the milling-machine table so that

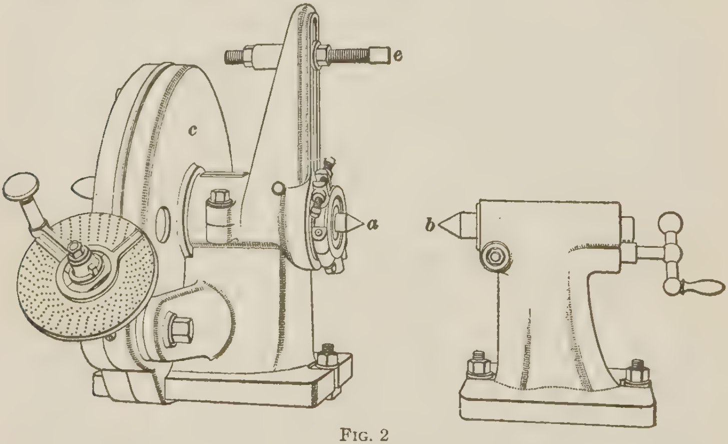


FIG. 2

the gear-blank may be held on an arbor between the centers *a* and *b*, or placed in the head-stock spindle. The indexing mechanism is shown at *c*. The thrust of the milling cutter is resisted by the screw *e*; this screw may be moved up or down the vertical guide and it may be moved in or out until the end rests against the rim of the wheel that is being cut. When the radius of a gear is much, if any, greater than the length of the vertical support for the screw *e*, this fixture will give insufficient support and a fixture similar to that shown in Fig. 3 had better be used. This fixture consists of a single part that is bolted to the milling-machine table so that the gears being cut lie horizontally. The turntable *a*, which may be turned by the indexing mechanism below it, is the support

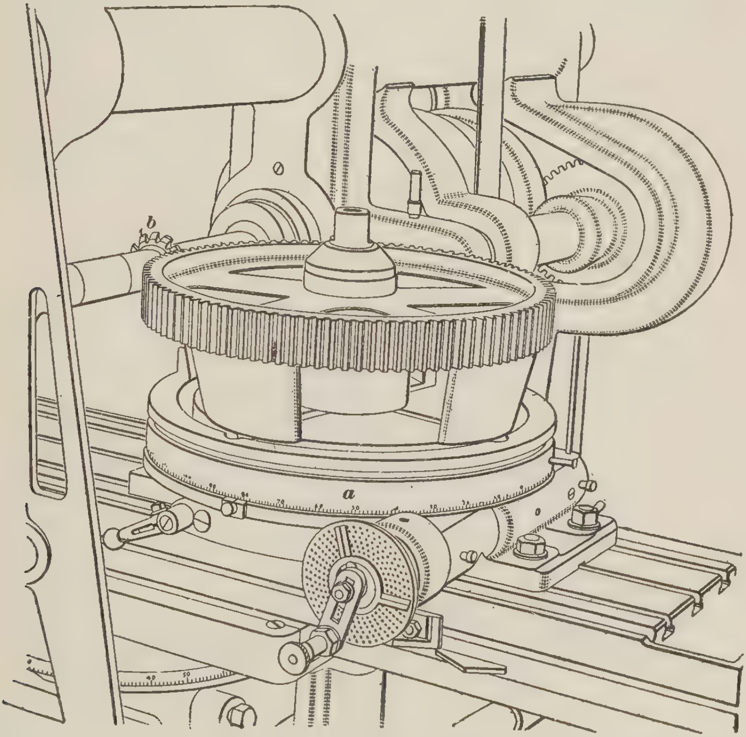


FIG. 3

upon which the gear-blank rests. The gear is fed vertically past the cutter *b*, one tooth space being cut at each pass.

8. In Fig. 4 is shown a form of milling machine especially adapted to gear cutting and known as an **automatic gear cutting machine.** The gear-blank is mounted on the arbor *a*, which is supported at the outer end in an adjustable bearing on the support *b*. The indexing worm-wheel is partly shown in the shield *c*. The cutter, not shown, may be mounted on the spindle *d* by removing the outboard bearing *e*. The carriage *f* may be moved in a direction parallel to the axis of *a*, either by the hand wheel *g* or by a power mechanism that is not shown. The support *h* may be so adjusted as to bear on the back side of the gear-blank and thus counteract the thrust of the cutter. This machine is so arranged that the motion of the carriage *f* is automatically reversed at the

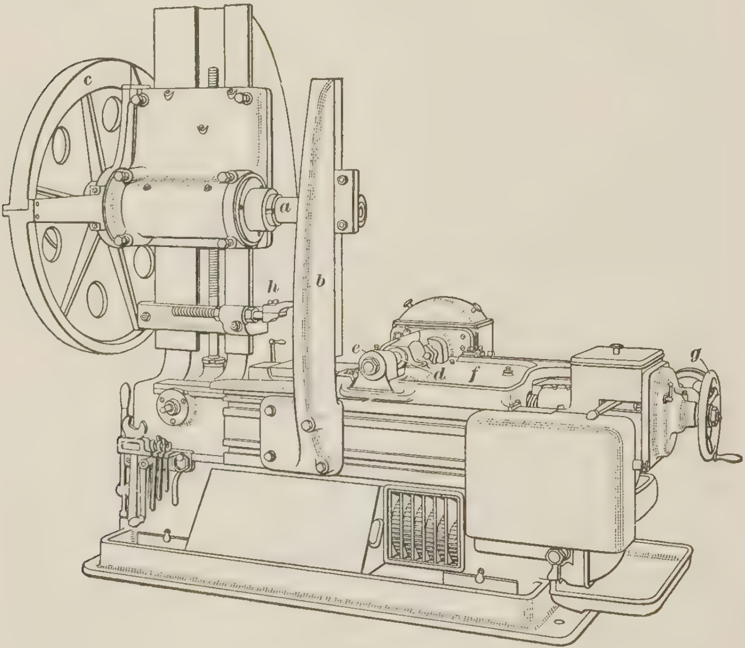


Fig. 4

end of each cut and is drawn back ready for a new cut. The gear is also indexed and the cutter fed through the work automatically, so that when the machine has been properly set up it will cut all around a gear without attention from the operator.

9. Involute Gear-Cutters.--The shape of the gear-tooth changes with the pitch and the number of teeth in the gear. For absolute accuracy, it is therefore necessary to have a separate cutter for every number of teeth and for every pitch. So great an outlay would be required for cutters under these circumstances that the milling process would be available for cutting gears only when a large number of gears of a given pitch and number of teeth are to be made. In practice it is found, however, that one cutter may be used to cut gears having several different numbers of teeth without introducing too great an error. In the $14\frac{1}{2}°$ involute system, eight cutters are commonly supplied for each pitch. These cutters will cut, with a fair degree of accuracy, any gear from a twelve-tooth pinion to a rack. Table III gives the range of the number of teeth for which each cutter is intended. The cutters are ordinarily made to cut gears of diametral pitches, but when necessary they may be made to cut common circular pitches.

TABLE III

STANDARD $14\frac{1}{2}°$ INVOLUTE GEAR-CUTTERS

Number of Cutter	Number of Teeth in Gear	Number of Cutter	Number of Teeth in Gear
1	135 to rack	5	21 to 25
2	55 to 134	6	17 to 20
3	35 to 54	7	14 to 16
4	26 to 34	8	12 to 13

10. When greater accuracy than these cutters will give is desired, special half-size cutters may be used. Table IV gives the range in the number of teeth for which each cutter is intended.

11. Standard Cycloidal Gear-Cutters.—In the cycloidal system, the shape of the tooth outline varies with the pitch and the number of teeth, and the variation is greater than in the involute system. It is not possible for any cycloidal cutter to cut as wide a range as is possible with any involute cutter. A set of standard cycloidal cutters therefore contains twenty-four cutters for each pitch, each cutter being designated by a letter. Table V gives the range in the number of teeth for which each cutter is intended. As in the case of the involute cutters, cycloidal cutters are commonly diametral-pitch cutters, but circular-pitch cutters may be had.

TABLE IV

SPECIAL 14½° INVOLUTE GEAR-CUTTERS

Number of Cutter	Number of Teeth in Gear	Number of Cutter	Number of Teeth in Gear
1	135 to rack	5	21 to 22
1½	80 to 134	5½	19 to 20
2	55 to 79	6	17 to 18
2½	42 to 54	6½	15 to 16
3	35 to 41	7	14
3½	30 to 34	7½	13
4	26 to 29	8	12
4½	23 to 25		

No half-size cutters are supplied in the cycloidal system. When greater accuracy is required than these cutters will give, special cutters must be made.

12. Sharpening Gear-Cutters.—After gear-milling cutters have become dulled by use, they may be sharpened by grinding on the radial face at the front of the cutting edge. If care is taken to keep this surface radial, the shape of the tooth produced by the cutter will not be changed. The grinding wheel should have its edge beveled so as to grind clear to the bottom of the tooth. This wheel should be put on an arbor with a shoulder and nut so that the flat grinding side will run true.

13. Centering the Cutter.—When starting to cut a gear, care must be taken that the cutter is central with the gear-blank. A cutter is *central* when its center line passes through the center of the gear-blank.

TABLE V

STANDARD CYCLOIDAL GEAR-CUTTERS

Letter of Cutter	Number of Teeth of Gear	Letter of Cutter	Number of Teeth of Gear
A	12	M	27 to 29
B	13	N	30 to 33
C	14	O	34 to 37
D	15	P	38 to 42
E	16	Q	43 to 49
F	17	R	50 to 59
G	18	S	60 to 74
H	19	T	75 to 99
I	20	U	100 to 149
J	21 to 22	V	150 to 249
K	23 to 24	W	250 and over
L	25 to 26	X	Rack

Gear-cutting machines are usually provided with an indicator by which the cutter may be set near enough to the center for most purposes. When the machine has no indicator, the cutter may be set central by one of the following methods: Place a true center in the work spindle and set the cutter so that its center line, which is scratched around the outer edge or on the back of the tooth, is in line with the point of the center. A more accurate method is to place a **V** center *a* in the work spindle and then set the cutter *b* so that it will just touch a tissue-paper feeler on each side as in Fig. 5. If the cutter must be absolutely central, it should be set as close as possible by the foregoing methods and the final adjustment made as follows: Put a blank in the machine and take a cut not quite the full depth of the tooth, as though making the gear. Then remove the blank, coat the sides of the cut with a thin coating of copper, reverse it and replace it in the machine. Do not clamp the blank in replacing, but let the cutter, as it is fed through the cut, center the blank. If the original cut was central, the cutter will scrape off all the copper; if it was not central, the copper will be taken off at the top of one side of the cut and the bottom of the other side. This indicates that the cutter needs to be moved toward the side from which the copper is being removed at the top of the cut. This last test should be repeated, making a new cut each time, until the copper is removed evenly all over the cut, thus indicating that the cutter is central.

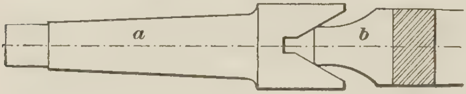


FIG. 5

The thin coating of copper just mentioned may be obtained by coating the surface with a solution of blue vitriol (copper sulphate) and water and allowing it to dry. Care should be exercised in handling blue vitriol, as it is poisonous and will probably produce a bad sore if it comes in contact with a place where the skin is broken.

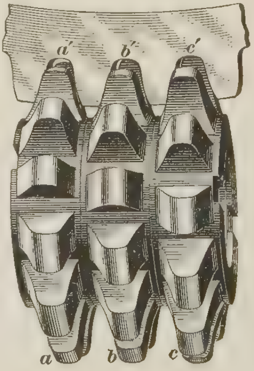


FIG. 6

14. Gang Cutters.—In order to cut gears more rapidly than is possible with a single cutter, gangs of two or three cutters are sometimes mounted on the same arbor. Fig. 6 shows a gang of three cutters. The central cutter *b* is an ordinary milling cutter, and is set central with the gear-blank; the cutters *a* and *c* are so shaped that the spaces they cut are radial in the gear. A gang of cutters can be used with only one size of gear, and will not be correct for a gear having any other number of teeth. When a gang cutter is used, the work is indexed for the same number of teeth as there are cutters in the gang. But the cutting cannot be done three times as fast as it would be with a single cutter, because more heat is generated with the gang cutter and a somewhat slower cutting speed must therefore be used.

Each cutter of a gang should be provided with two keyways, one placed so that the cutter teeth will be lined up for convenience in grinding the radial faces of the teeth, and the other keyway staggers the teeth, as shown in the illustration. The teeth should always be staggered when mounting the cutters for work, as the cutting strain is in that way somewhat reduced and rendered more uniform, thus permitting more accurate work.

HOBBING PROCESS

15. Spur-Gear Hobbing Machine.—The hobbing machine shown in Fig. 7 is a machine for the generation of gear-teeth by the milling process, and resembles in many respects the automatic gear-cutting machine described in Art. **8.** In the machine shown in Fig. 7 a number of gears are being cut at the same time. The gear-blanks are mounted side by side on a mandrel that is held in the chuck *a* on the end of the spindle of the machine and the outer end of the mandrel is supported by the arm *b*. Hobbing spur gears differs from the milling of the same kind of gears in that the blanks are not indexed after each cut; but, instead, the gears and the gear-cutter must rotate together with a certain definite velocity ratio that is obtained by means of gearing. In order that this velocity ratio may be changed to permit gears of different sizes to be cut, change gears are provided in the guard *c*. The carriage *d* on which the cutter *e* is mounted may be moved lengthwise of the machine either by means of the hand wheel *f* or automatically. When hobbing spur gears, the axis of the cutter is not at right angles to that of the gears, but is set at a slight angle. To permit the setting of the cutter at the proper angle, the upper part of the carriage is arranged to turn in a horizontal plane and the angle set by the scale shown at *g*.

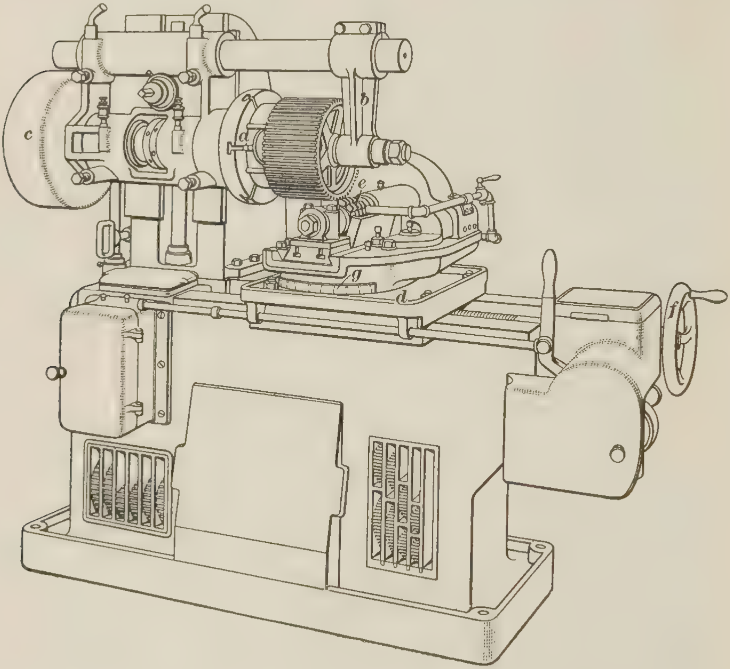


Fig. 7

16. The Hob.—In the involute system, the worm-tooth has straight sides. If a worm is properly grooved in a lengthwise direction and the teeth thus formed are relieved so that the cutting edge is the only part that touches the work, the worm has been turned into a hob. Fig. 8 illustrates a hob. The worm of which a hob is made may have one, two, or three threads; however, it is usually single-threaded. There is one important difference between a worm and a hob; the outside diameter of the hob is larger than that of the corresponding worm by an amount equal to twice the bottom clearance to be provided in the gear that is being cut.

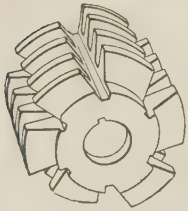
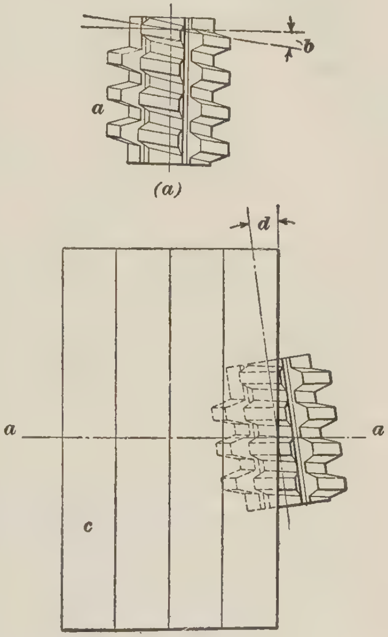


Fig. 8

17. Hobbing-Machine Operation.—In Fig. 9 (*a*) let *a* represent a hob in which *b* is the angle of the thread. In Fig. 9 (*b*) the observer is supposed to be looking down on the gears that are being cut in Fig. 7, the axis of the gears being shown at *a a* and the gear-blanks at *c*. If these gears were being cut by the ordinary milling process, the axis of the cutter would be at right angles to the axis *a a*, but when the hob is to be used, its axis must be set so that the angle *d* is equal to the angle *b*.

If a single-threaded hob is being used, every revolution of the hob will move one tooth of the gear that is being cut past a fixed point. As many turns of the hob will therefore be required as there are teeth in the gear being cut to cause the gear to revolve one turn, and the change gears must be arranged to give this ratio between the work spindle and the hob. If, while the gear-blanks and hob are rotating, the hob is fed across the face of the gears, correct involute teeth will be cut on them.



(*a*)

(*b*)

Fig. 9

SHAPING PROCESS

18. A **gear-shaper** uses a cutter having teeth of the same shape and size as the teeth of the gear with which the one that is being cut is to work. This machine does not reproduce the shape of the cutter tooth in the gear, but, instead, cuts a tooth that will work properly with a gear having teeth of the same shape as the teeth of the cutter.

In the gear-shaper shown in Fig. 10, the cutter *a* is carried on the end of the ram, which moves vertically during the cutting stroke in guides on the head *b*. The gear that is being cut is shown at *c*. It is mounted on a spindle parallel to the line of motion of the cutter, and the correct distance between the center of the gear and that of the cutter is obtained by moving the head *b* on the cross-rails *d*. The cutter usually cuts on the up stroke, though it may be made to cut on the down stroke when necessary. When cutting on the up stroke, the force of the cut is resisted by the adjustable jack *e*. When the machine is in operation, the cutter and the gear that

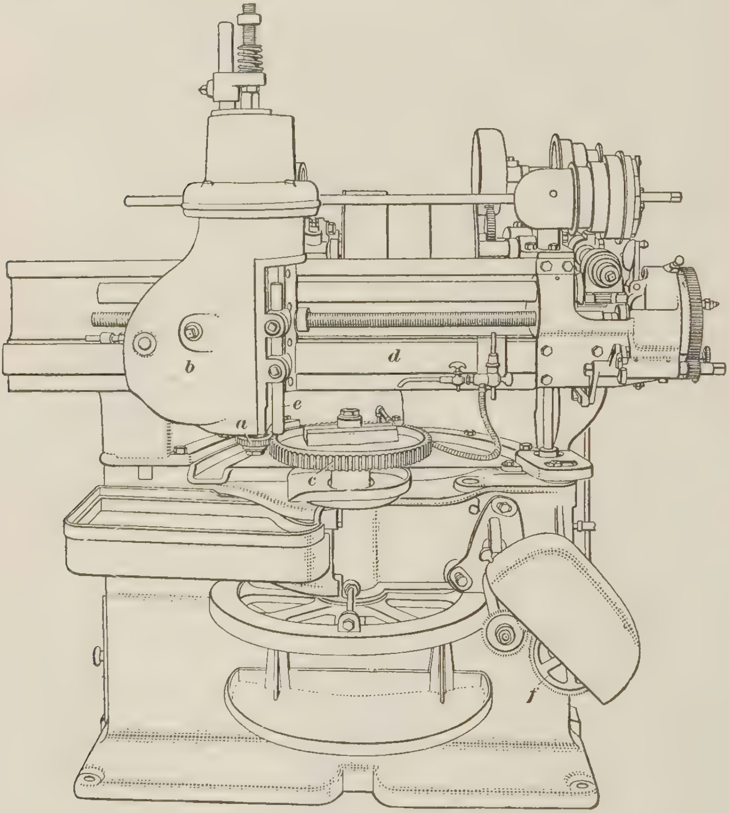


FIG. 10

is being cut are rotated continuously, as though they were two gears in mesh, the proper relation being maintained by gearing, and the depth feed is automatically thrown out when the cutter has been fed to the correct depth. The velocity ratio between the cutter and the gear may be changed by the change gears at *f*, so that gears having different numbers of teeth may be cut. For the purposes of the following explanation, it has been found convenient to assume that the cutter and the gear are rotated slightly after each cut.

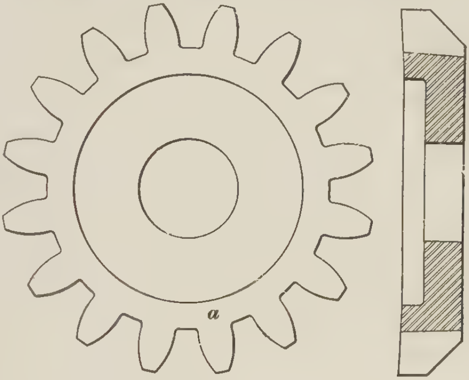


FIG. 11

19. In Fig. 11 is shown a **gear-shaper cutter** that resembles a gear in many respects. The tooth outline is the same as that for a gear having the same pitch and the same system of tooth outlines. The cutter teeth are, however, not the same thickness throughout the width of the cutter. They are tapered from the front, which is the cutting edge, to the back. The outside diameter of the cutter is larger than the outside diameter of the gear, having the same pitch and number of teeth, by an amount equal to twice the bottom clearance to be provided in the gear being cut. The cutter may be sharpened by grinding on the flat face *a* without changing the shape of

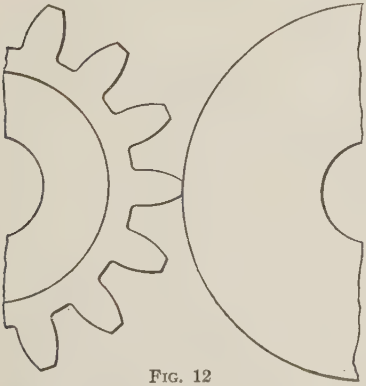


FIG. 12

the tooth outline that is cut. One of these cutters will cut any gear of the same pitch and system of tooth curves, no matter what the number of teeth, and it is therefore necessary to buy only one cutter for each pitch it is desired to cut.

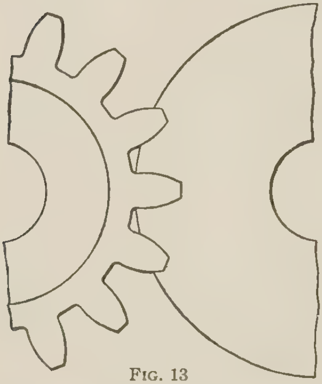


FIG. 13

20. Gear-Shaper Operation. After the gear-shaper is correctly set up and the machine adjusted so that the cutter moves radially into the work, the process of cutting the gear may proceed as follows: The cutter and the gear-blank are in the positions shown in Fig. 12, the cutter being just about to enter the blank. The machine is then started, moving the cutter up and down, but not rotating either the cutter or the gear-blank, and the cutter is fed into the work until the required depth of cut has been produced, as shown in Fig. 13. The cutter and the gear-blank are then started rotating in the manner explained in Art. **18.** The teeth on the cutter then cut teeth on the gear in the manner illustrated in Fig. 14.

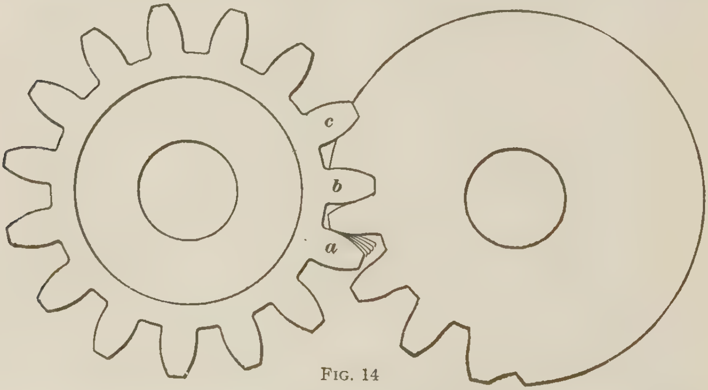
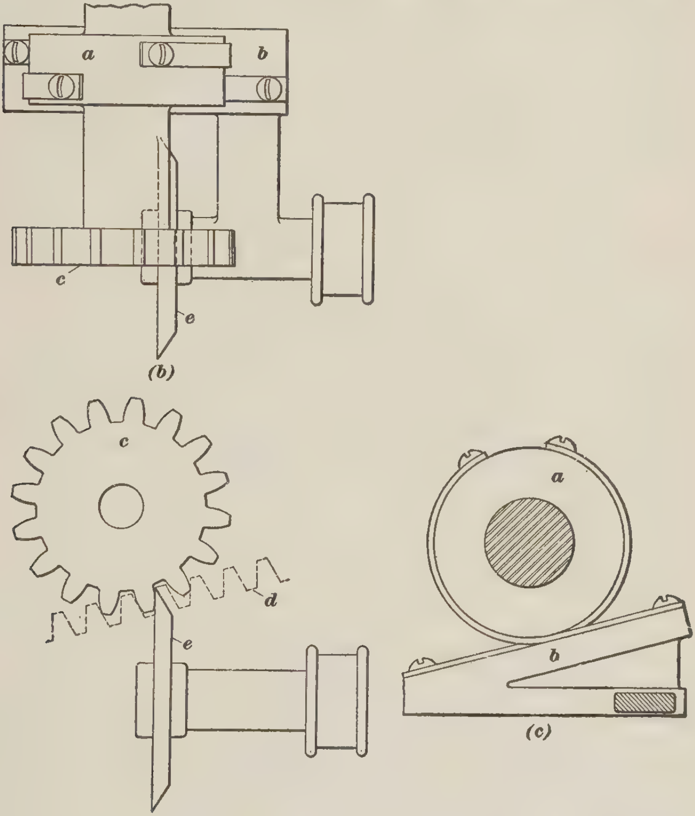


FIG. 14

In order to understand the action of this cutter, the relative motions assumed for the cutter and gear-blank must be clearly understood. The cutting motion of the ram to which the cutter in Fig. 14 is attached, is perpendicular to the plane of the gear; but just before the beginning of each cutting stroke the cutter and the gear are rotated slightly, as though their pitch lines rolled together. As these motions proceed, the teeth of the cutter generate the teeth on the gear. While the cutter tooth *a* has been cutting one side of a tooth on the gear, the tooth *b* has been cutting the other side of the same tooth, and the cutter teeth *b* and *c* are just starting to cut the next following tooth. Each tooth in the cutter, as it passes the center line cuts the root of a tooth in the gear; but the flat space at



(b) (a) (c)

FIG. 15

the root of the cutter teeth does not touch the point of the gear-teeth at any time, as these are turned to size.

21. Grinding the Gear-Shaper Cutter.—After they are hardened, the gear-shaper cutters must be ground. Fig. 15 illustrates diagrammatically a machine for grinding the teeth on hardened gears and cutters and for generating the true involute tooth outline. Fig. 15 (*a*) is an elevation of the machine, and Fig. 15 (*b*) is a plan view. The part of the machine shown in Fig. 15 (*c*) belongs directly behind that shown in view (*a*). The cylinder *a* is of the same diameter as the pitch circle of the cutter to be ground and is mounted on the same shaft with it. When the cylinder *a* is rolled on the block *b*, the same motion is given to the gear *c* as if it rolled on the imaginary rack *d* that is shown in dotted lines. The grinding wheel *e* is set so that its flat face coincides with one of these rack teeth, and it therefore grinds the correct involute tooth outline. The angle between the top and bottom faces of the block *b* is the same as the angle of the involute that is to be ground. If a cycloidal gear is to be ground, the grinding wheel must be formed to the shape of the cycloidal rack tooth of corresponding pitch; hence, this method of grinding is not so well adapted for use with cycloidal cutters.

INTERNAL GEAR AND RACK CUTTING

22. The teeth of *internal gears* are on the inside of the rim and have the same shape as the spaces between the teeth of spur gears having the same pitch and number of teeth. Internal gears are most easily cut by some planer or shaper method, though the milling process may be used. When internal gears are milled, special cutters and a fixture that will permit feeding the cutter through the gear must be provided, and there must be sufficient room for the cutter to run clear through the working part of the gear-tooth. Internal gears may be cut on the gear-shaper with the same cutter as is used for cutting spur gears. Internal gears that are cut on a gear-shaper will mesh properly with a spur gear of the same pitch and will have all necessary clearances.

23. Rack Cutting.—Racks may be cut by any of the methods described for the cutting of spur gears, provided the machine is arranged to space the rack square across the path of the cutter.

Short racks can be cut readily in the horizontal milling machine, using the cross-feed screw to obtain the spacing and the regular longitudinal-feed screw for feeding. The rack blank may either be clamped to the table or be held in the vise or in a special fixture.

When racks are too long to be cut in this manner, a special rack-cutting attachment, one form of which is shown in Fig. 16, may be used. The cutter *a* is placed at right angles to its normal position; this allows the feed-screw *b* to be used for spacing the teeth and the cross-feed screw for feeding. A graduated dial *c* reading to .001 inch is placed on the feed-screw, and the correct spacing is obtained by means of it. The rack may be placed in a fixture *d* made as shown, which will take several racks at one time.

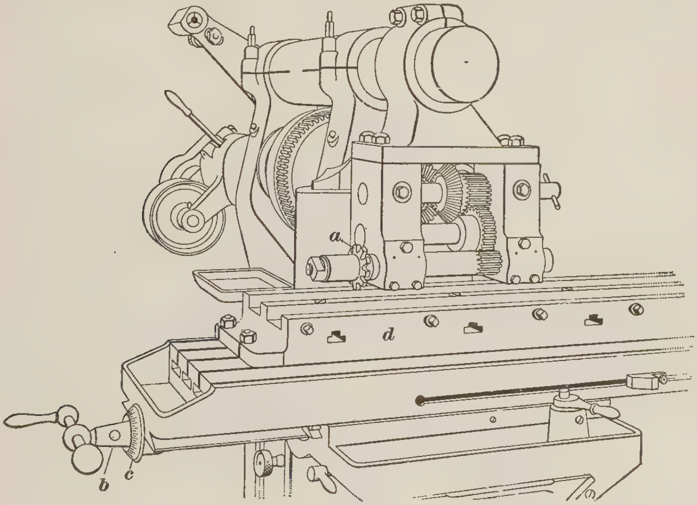


FIG. 16

24. When racks are cut in the milling machine, it is strongly recommended that the gibs of the part that is moved to obtain the spacing be set up more firmly than usual, so as to create enough friction to prevent any shifting, which is liable to occur by reason of the backlash of the feed-screw.

Racks are often cut in milling machines of the planer type; in that case, the spacing is obtained by means of the feed-screw in the cross-rail. The head should then have its gibs set up rather firmly. The rack is placed square across the platen.

A planing tool formed to the correct shape of the space may be used in a planer, shaper, or slotter, obtaining the spacing by means of whatever feed-screw can be used for the purpose.

The gear-shaper may be used to cut the teeth of short, fine-toothed racks by using a special fixture for that purpose. This fixture is arranged so that it moves the rack past the cutter as it would move if it were a finished rack and the cutter a gear with which it was working. If the length of the rack to be cut is greater than the motion of the vise of the fixture, the rack may be set ahead when it has been cut as far as the fixture will move, matching a tooth of the cutter in the last space of the rack and setting the vise back to the beginning of its movement. To get the tooth to match exactly in the last space that was cut before resetting, it will be well to copper the sides of the cut in the manner explained in Art. **13** and then set the cutter so that it will barely scrape the copper off. This method of setting the rack ahead applies to all machines that are adaptable to rack cutting.

HELICAL GEAR CUTTING

MILLING PROCESS

25. Selecting the Cutter.—Helical gears may be cut in a universal milling machine by using the spiral milling head shown in Fig. 17. The number of teeth for which to select the cutter may be found by applying the following rule:

Rule.—*To find the number of teeth for which to select the cutter for a helical gear, divide the number of teeth in the gear by the cube of the cosine of the tooth angle.*

Example.—What involute gear-cutter should be used to cut a helical gear having 30 teeth and a tooth angle of 25°?

Solution.—The cosine of 25° is found from a table of cosines to be .9063, the cube of which is .7444. Applying the rule, the number of teeth for which to select the cutter is $30 \div .7444 = 40.3$. As a gear must have a whole number of teeth, the cutter is selected for a gear having 40 teeth, and Table III shows that a No. 3 cutter should be used. Ans.

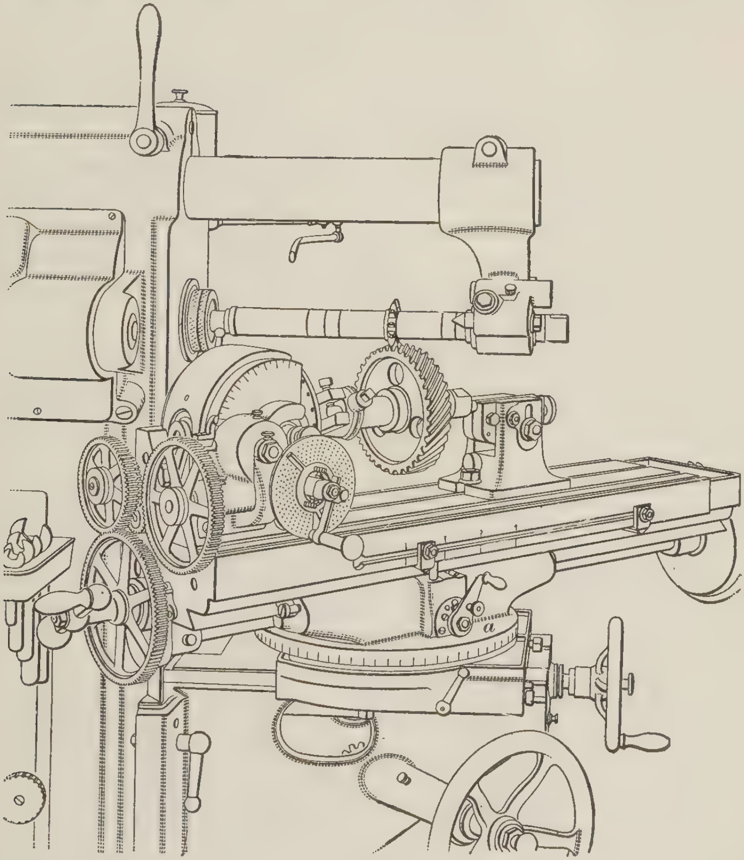


Fig. 17

26. Setting Up to Cut Helical Gears.—A universal milling machine set up to cut helical gears is shown in Fig. 17.

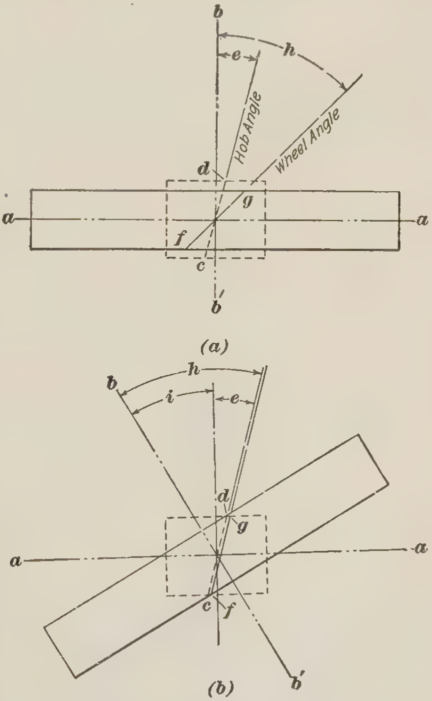
In setting up such a machine, it is first necessary to mount the cutter on its arbor and put it in place in the machine. The table should be set at right angles to the axis of the arbor, and the spindle of the index head set central with the cutter by any of the methods explained in Art. **13.** This spindle may be brought central with the cutter by means of the cross-feed screw and that adjustment should then be firmly clamped. The table may then be turned to one side, as shown in Fig. 17. When the table was at right angles to the cutter arbor, the scale at *a* read zero; when the table has been turned to cut the helix, the angle of the helix should be set on scale *a*. For example, if the tooth angle is 25°, the 25° mark on scale *a* should be brought up to the zero mark on the saddle casting, and the table will then have been turned through that angle. If the helix that is to be cut is right-handed, turn the table to the right from the zero position. If, on the other hand, the helix is left-handed, turn the table to the left.

27. When milling helical gears, the gear-blank must be rotated while the cut is being taken. In order that it may rotate at the right speed, the spindle of the index head is connected by gearing to the work spindle, the gears to produce the correct rotation of the work are found by following instructions furnished with the milling machine.

The cutter should now be set to the correct depth of cut. The depth of the cut may be adjusted by raising and lowering the milling-machine table, as may be required. The cutter should be set to cut toward the index head and not toward the foot-stock, as the work will be better supported and play or backlash in the driving connections will be prevented. After having finished a cut, the cutter should not be taken back through the cut because the unavoidable lost motion in the gears, etc. will likely cause interference between the cutter and the work. It is therefore necessary to lower the work, return to the starting position, and raise the table to the position for the correct depth of cut. Then, when the work has been indexed one tooth, another cut may be taken. It is advisable to index a gear clear around, nicking it slightly at each tooth, before any cutting is done, so that any error in indexing will be discovered before the blank is spoiled. To produce accurate work, it is advisable to take at least two cuts, making the second or finishing cut a very light one.

HELICAL GEAR HOBBING

28. Teeth of helical gears may be cut by hobbing, either a hobbing machine or a milling machine being used. When the milling machine is employed, it may be set up the same as for milling a helical gear, except in the following respects: When the helixes of the hob and the gear or wheel are of the same hand—that is, both right-handed or both left-handed helixes—turn the table through an angle equal to the difference between the tooth angle of the wheel and the thread angle of the hob. When the tooth angle of the wheel is larger than the thread angle of the hob, turn the table in the same direction as the hand of the helixes; and when the angle of the hob thread is larger than that of the wheel tooth, turn the table in the opposite direction to the hand of the helixes.



(a)

(b)

FIG. 18

29. When the helixes of the hob and the wheel are of different hands, turn the table through an angle equal to the sum of the tooth angle of the wheel and the thread angle of the hob. When the sum of these angles is less than 90° turn the table in a direction opposite to the hand of the hob thread; but when the sum of these angles is more than 90° turn the table in the same direction as the hand of the hob helix and through an angle equal to 180° minus the sum of the tooth angle and the thread angle of the hob.

It will sometimes be found impossible to turn the milling-machine table far enough to permit a gear to be hobbed, in which case the table should be turned as far as possible and a fixture used that permits the cutter to be turned far enough to make up the difference.

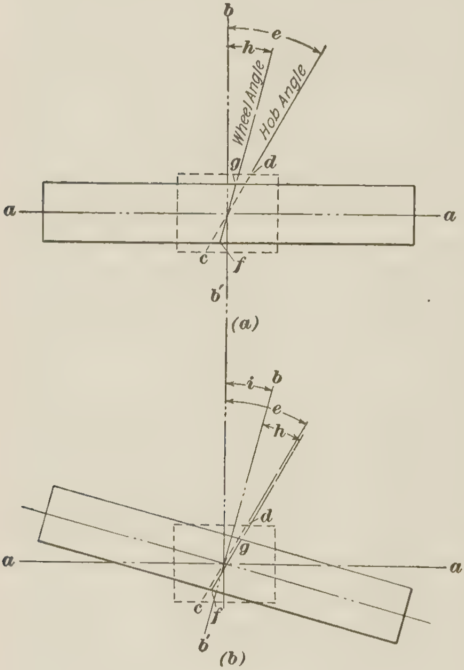
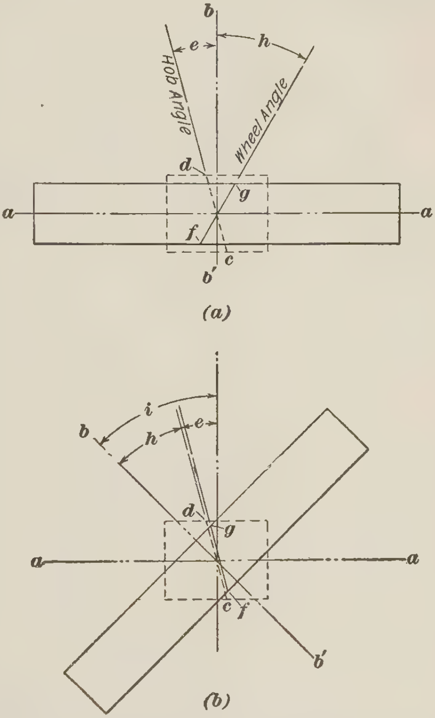


Fig. 19

30. The application of these principles will become evident by considering the following cases: In Fig. 18 (*a*), the axis of the hob is shown at *a a* and that of the gear at *b b*, the two standing at right angles to each other. The gear, it must be remembered, is mounted on the milling-machine table and is turned in the plane of the paper with it. In this and the following illustrations, the hob is supposed to be above the gear and is shown in dotted lines. The angle of the teeth on the hob is shown by the dotted line *c d*, which represents one tooth. This tooth is on the bottom side of the hob and will cut a space in the wheel when the milling-machine table has been set to the correct angle. The angle *e* is therefore the thread angle of the hob. The thread angle of the hob, in this and the following figures, is made much larger than is common, in order to make the illustrations clear. The angle of the tooth of the gear next to the space that will be cut by the hob tooth *c d* is shown by the line *f g*, and *h* is therefore the tooth angle of the gear. When the axis of the gear is at right angles to that of the hob, the hob will cut correct teeth on the wheel only when the thread angle of the hob equals the tooth angle of the gear. In order that this hob may cut teeth parallel to *f g*, the milling-machine table must be swung to the right through the angle *i*, Fig. 18 (*b*). This angle is the difference between the angle *h* and the angle *e* in Fig. 18 (*a*). Since the helixes of both the hob and the gear are right-handed and the angle of the gear tooth is larger than the helix angle of the hob, this setting of the table is in accordance with the principles explained in Art. **28**.



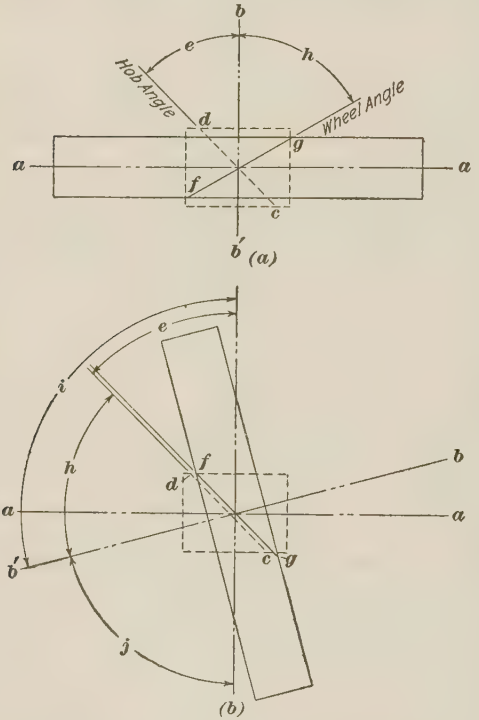
(a)

(b)

FIG. 20

Fig. 19 is exactly like Fig. 18, except that the angle of the hob thread is larger instead of smaller than the tooth angle of the gear; but the letters refer to the same points and angles as in the former illustration. In this case, however, the table must be turned to the left, which is again in accordance with the principles explained in Art. **29**.

31. A right-handed wheel and a left-handed hob are shown in Fig. 20. The notation is the same as in the two former illustrations. By referring to Fig. 20 (*a*), it will be seen that the milling-machine table must be turned through an angle equal to the sum of the tooth angle of the gear and the thread angle of the hob. Fig. 20 (*b*) shows the position of the gear when the table has been set, the axis of the gear having been turned through the angle *i*.



(*a*)

(*b*)

FIG. 21

Fig. 21 shows a gear having a right-handed thread and a hob having a left-handed thread, the sum of the angles being more than 90°. Although the teeth may be brought together by turning the table through an angle equal to the sum of the tooth angle of the gear and the thread angle of the hob, it is usually better to turn the table in the same direction as the hand of the hob thread, through an angle equal to 180° minus the sum of the tooth angle of the gear and the thread angle of the hob. This has been done in Fig. 21 (*b*), the gear having been turned through the angle *j* instead of the angle *i*.

32. When the machine is so constructed that the table cannot be turned far enough to permit the hob to cut the gear, it may be turned as far as possible and the hob turned the rest of the way. Suppose that a left-handed hob having a thread angle of 15° is to be used to cut the teeth on a right-handed gear having a tooth angle of 45°, but that the milling-machine table can be turned only 45° from the middle position. According to the principles already explained, the milling-machine table should be turned 45+15=60° to the right, as shown by the angle *i*, Fig. 22 (*a*). Since the table can be turned only 45°, as shown by the angle *j* in Fig. 22 (*b*), the hob is turned in the opposite direction through the angle *k*, which is 60−45=15°.

In order to produce the most accurate results when hobbing gears, it is best to connect the hob and the gear with gearing so that they will be maintained in correct relations to each other. The hob may sometimes be made to drive the gear as though it were the worm with which the gear might mesh, when the wheel is previously gashed with an ordinary milling cutter, thus leaving only a comparatively small amount of metal for the hob to remove.

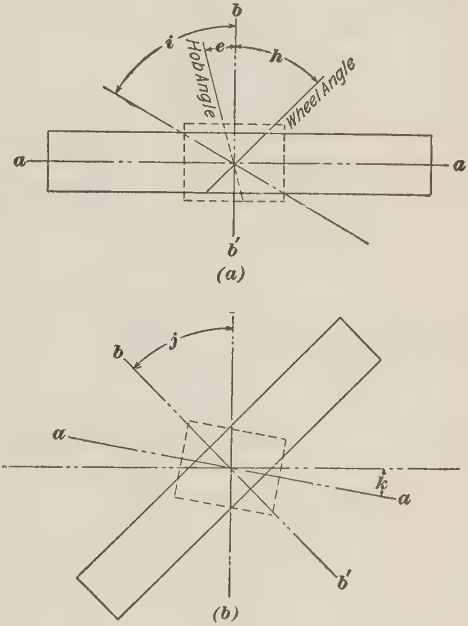


FIG. 22

If the hobbing is to be done on a special hobbing machine, the machine must be set up according to the builder's directions.

Hobbing machines differ so greatly in design that no specific rules can be given for their operation.

BEVEL-GEAR CUTTING

MILLING PROCESS

33. Selecting the Cutter.—Bevel gears may be either planed or milled. The milling process does not, however, produce correct outlines for bevel-gear teeth. If the cutter is the correct size and shape for the large end of the teeth, it will not produce the correct outline at the small end of the teeth because the cut is not so deep as it was at the beginning. While bevel gears cut with a milling cutter are only approximately correct, the comparative cheapness of this method has led to its being largely used. The ordinary cutters made for spur gears should never be used for cutting bevel gears, as they will cut the teeth entirely too thin at the small end. Special bevel-gear cutters are made for this purpose; these cutters are of the involute form, but thinner than the standard cutters. They are numbered from 1 to 8, and cover the same range in the number of teeth as the standard involute cutters described in Art. **9.** A bevel-gear cutter cannot be selected directly in accordance with the number of teeth of the bevel gear. It is selected, instead, for a number of teeth that is calculated by one of the following rules:

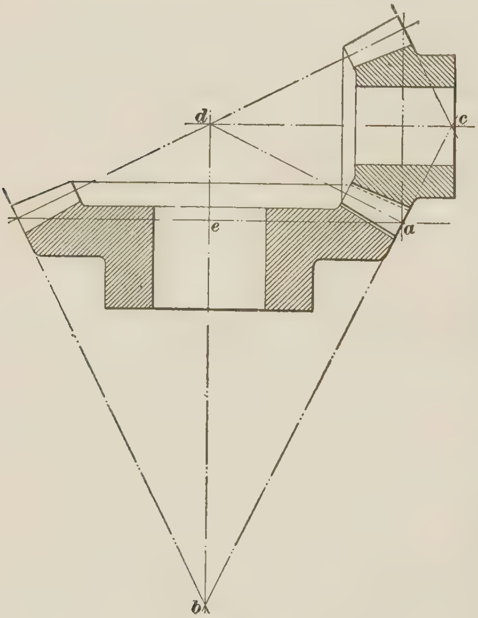


FIG. 23

Rule I.—*To find the number of teeth for which a bevel-gear cutter is to be selected, divide the number of teeth of the bevel gear by the cosine of the center angle a d e, Fig. 23.*

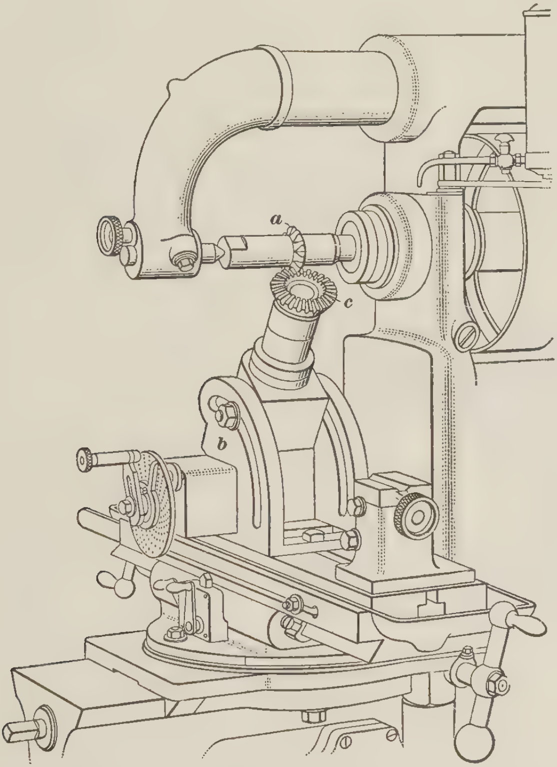


FIG. 24

EXAMPLE.—The center angle of a bevel gear having 24 teeth is 53° 10′′. For what number of teeth should the cutter be selected?

SOLUTION.—The cosine of 53° 10′′ is .5995. Applying the rule gives $24 \div .5995 = 40$ teeth. Referring to the Table of Standard Cutters it is found that for gears having between 35 and 54 teeth, a No. 3 cutter is to be employed. Hence, use a No. 3 bevel-gear cutter. Ans.

Rule II.—*To find the number of teeth for which a bevel-gear cutter is to be selected when the slant height a b of the back cone is known, multiply the slant height of the back cone by two and by the diametral pitch.*

Example.—The slant height of the back cone of a bevel gear is $4\frac{1}{2}$ inches and the teeth are 8 diametral pitch. For what number of teeth should the cutter be selected?

Solution.—Applying the rule gives $4\frac{1}{2} \times 2 \times 8 = 72$ teeth. Referring to the Table of Standard Cutters, it is found that for gears having between 55 and 134 teeth, a No. 2 cutter is employed. Hence, use a No. 2 bevel-gear cutter. Ans.

34. Setting the Cutter.—The cutter *a*, Fig. 24, is placed on an arbor in the spindle of a milling machine, and set central with the spindle of the index head *b* by any of the methods explained for spur gears in Art. **13.** The gear-blank is next placed on an arbor in the spindle of the index head and the spindle tilted to the cutting angle, as is shown in Fig. 24. Lines showing the depth to which the cut is to be taken are now scribed on each end of the gear by means of gauges like the one shown in Fig. 1 (*c*), and a cut is taken to the full depth indicated by these lines. The blank is then indexed one tooth and another cut is taken. These two cuts are shown at *b* and *c* in Fig. 25 and they block out the tooth *a*. This tooth is, however, too thick at the large end and of incorrect shape at the small end.

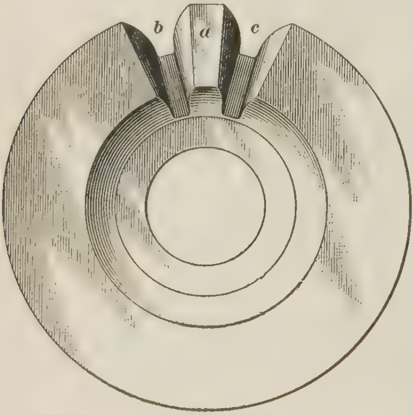


Fig. 25

35. Offsetting by Trial.—To correct the width of the tooth, the gear-blank must be so set that the cutter cuts on one side only. This may be done by setting the blank to one side of the center of the cutter. Fig. 26 is a diagrammatic illustration by means of which this offsetting may be explained. For convenience, the surfaces of the tooth *a* are each represented by a line on the pitch surface of the gear. The dotted lines *d e* and *f g* represent the sides of the slot *b*, Fig. 25, that was cut by the first pass of the cutter. In a like manner, the lines *h i* and *j k* represent the slot *c* that was cut by the first pass of the cutter after the gear-blank had been indexed one tooth.

36. The width *e i* of the tooth *a* is greater than the width *f e* of the space *b*. The width of the tooth must therefore be reduced at the large end and the width of the space at the same point must be increased until the tooth and the space are the same width. If the thickness of the cutter is not the same as the width of the space at the small end, the tooth will also have to be changed at that end. To reduce the thickness of the tooth at the large end, set the gears so that the cutter is in position to enter the slot *b*, and then adjust the gear by means of the cross-feed screw so that the tooth *a* will be moved away from the cutter. The amount of offset is found in one of the ways that will be explained presently. Then index the gear until the required cut is taken at the inner end of the tooth *a*. This setting has the same effect that would be produced if the center of the cutter moved in the line *l m*. If the gear were indexed so that the cutter just entered the inner end of the slot, the side of the tooth *a* would be cut back to *d n*. When a cut is taken at the inner end of the tooth, more metal will be removed from the tooth as the large end is approached.

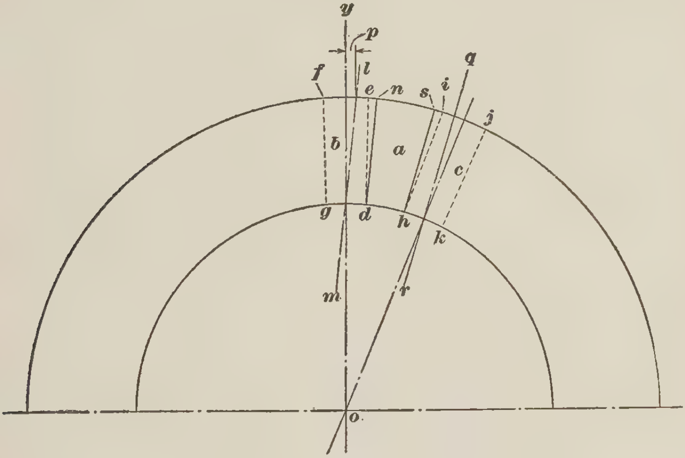


Fig. 26

37. To cut the other side of the tooth, the gear is then moved by the cross-feed screw until the cutter is offset a distance equal to p, but on the other side of the vertical center line $o\,y$, and the gear is indexed twice as much as before, so as to bring the left side of the space b up to the cutter, and it is then indexed one tooth, so as to cut from the right side of the tooth a. This setting is equivalent to making the cutter move in the direction of the line $q\,r$, and when the cut has been taken the side of the tooth will have been cut back to the line $h\,s$ or to one corresponding to $d\,n$ on the other side of the tooth. When offsetting, care must be taken to have the lost motion in the cross-feed screw always taken up in the same direction and the table clamped so that the work cannot be forced back from the cutter.

The thickness of the tooth at each end should equal the width of the space at that end, and these thicknesses may be measured by gear-tooth calipers or by gauges made of sheet metal. The sheet-metal gauges are made by cutting slots having depths equal to the corrected addendums of the tooth at the ends, and widths equal to the tooth thicknesses on the pitch line.

38. Offsetting by Trial.—The amount of offset for a bevel-gear cutter may be found by trial. The cutter is offset first to one side and then an equal amount to the other and trial cuts taken with each setting as was explained in Art. **37.** If the width of tooth produced by the first trial offset is not correct, new trials should be made until the setting that gives the correct thickness of tooth has been found. Cuts should then be taken around the gear with the cutter offset first in one direction and then an equal distance in the other. For the finer pitches, it is not necessary to take the central cuts excepting to obtain the correct setting; but in the coarser pitches, the central cuts are advisable and they are followed by offset cuts, as just described.

39. Offsetting by Calculation.—The required amount of offset may be obtained either by trial, as already explained, or it may be calculated approximately by the use of Table VI

TABLE VI

FACTORS FOR CALCULATING THE OFFSET OF BEVEL-GEAR CUTTERS

Number of Cutter	Slant Height of Pitch Cone ÷ Face of Bevel Gear-Tooth												
	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.50	6.00	7.00	8.00
1	.254	.254	.255	.256	.257	.257	.257	.258	.258	.259	.260	.262	.264
2	.266	.268	.271	.272	.273	.274	.274	.275	.277	.279	.280	.283	.284
3	.266	.268	.271	.273	.275	.278	.280	.282	.283	.286	.287	.290	.292
4	.275	.280	.285	.287	.291	.293	.296	.298	.298	.302	.305	.308	.311
5	.280	.285	.290	.293	.295	.296	.298	.300	.302	.307	.309	.313	.315
6	.311	.318	.323	.328	.330	.334	.337	.340	.343	.348	.352	.356	.362
7	.289	.298	.308	.316	.324	.329	.334	.338	.343	.350	.360	.370	.376
8	.275	.286	.296	.309	.319	.331	.338	.344	.352	.361	.368	.380	.386

and the following rule, which gives results that are usually within working limits of the correct offset. If the calculated offset does not give the correct tooth thickness, the offset must be adjusted by trial, as in the preceding method. In order to obtain from Table VI the number to be used when applying the rule, divide the slant height *a d*, in Fig. 23, by the length of the face of the tooth, and look in the column headed by the number nearest to the one thus obtained. Then find the factor in this column opposite the number of the cutter after which the following rule may be applied:

Rule.—*To find the offset of the milling cutter, divide the factor from Table VI by the diametral pitch and subtract the result from half the thickness of the cutter at the pitch line.*

The thickness of the cutter may be measured by means of a gear-tooth caliper. The calipers should be set to measure at a depth equal to the depth of cut minus the corrected addendum of the tooth that is produced by the cutter.

EXAMPLE.—What should be the offset of a No. 6 4-pitch bevel-gear cutter that is .262 inch thick at the pitch line when cutting a bevel gear in which the length of the face of the tooth is 2 inches and the slant height of the pitch cone is 9 inches?

SOLUTION.—The ratio of the slant height of the pitch cone to the length of the face of the teeth is $\frac{9}{2} = 4.50$. Turning to Table VI and looking in the column headed 4.50, find opposite the No. 6 cutter that the factor is .337. Applying the rule just given, the offset is

$$.262 \div 2 - .337 \div 4 = .047 \text{ in.} \quad \text{Ans.}$$

40. Correcting the Tooth Curves.—This method of cutting leaves the small end of the tooth of the correct width at the pitch line, but too thick at all points outside of the pitch line. This part of the tooth is commonly filed to the correct shape, but the following method may be used if desired. A spur-gear cutter of the same number as the first cutter used, but of a finer pitch is employed, the pitch being chosen according to the following rule:

Rule.—*To find the pitch of the cutter with which to correct the shape of the small end of the teeth, divide 2.157 by the depth measured at the small end of the tooth.*

The gear is then centered with this cutter, and the index spindle is tilted so that the end of the cutter tooth will run out at the top of the gear-tooth when about one-half or two-thirds of the way through the gear. The side of a bevel gear-tooth is shown in Fig. 27 (*a*). The unshaded part *a b c d* shows the portion that is correct when left by the first cutter, and the shaded portion *a b e* shows the part that must be corrected. When the last cutter is run through the gear, part of this surface is corrected; but the portion *a b c* in (*b*) remains to be corrected. The curves at the tooth ends are now correct and may be used as guides in the filing of the rest of the tooth.

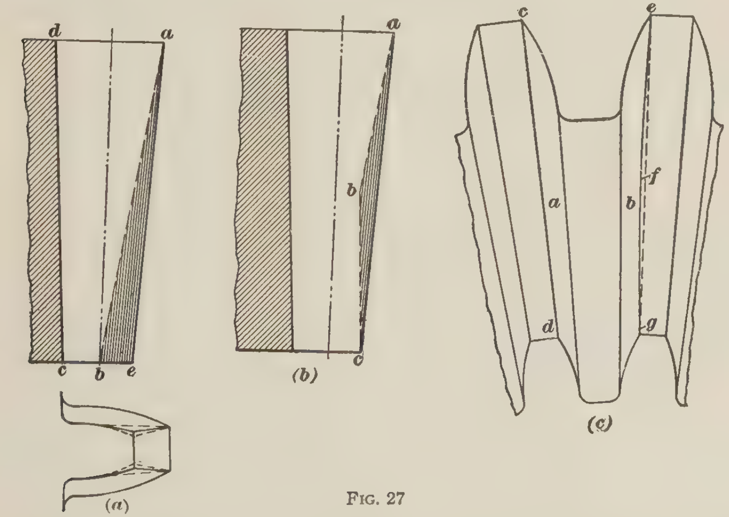
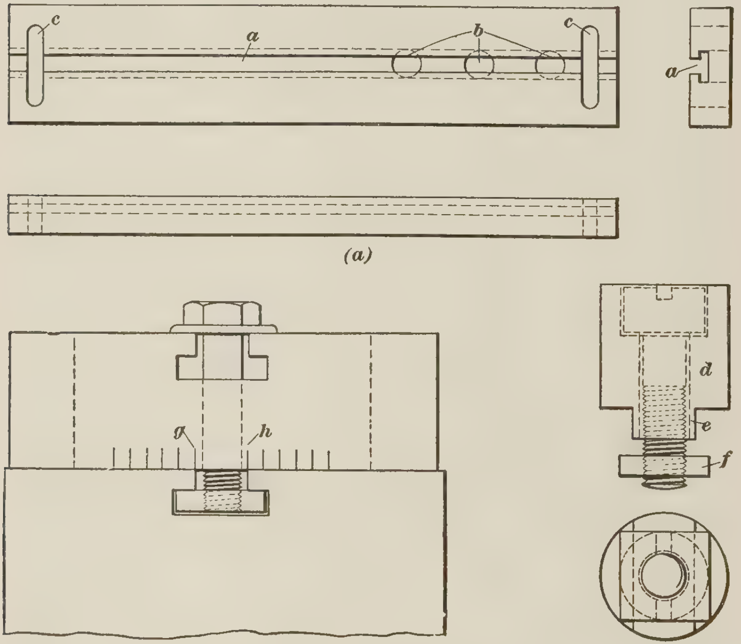


FIG. 27

Fig. 27 (*c*) shows a part of two teeth, the view being taken looking down in the space between them. The surface *a* has been corrected by filing, but the surface *b* remains to be filed. The edge *c d*, where the tooth surface has been corrected, is a straight line; but the edge *e f g*, when the tooth has not been filed, is curved. The amount of curvature is, however, exaggerated to make the illustration clearer. The surface *b* must be filed until the edge *e f g* has been moved back to the dotted line *e g*; but the tooth curves at the ends must not be changed.

41. Swiveling Method.—A special fixture is sometimes used to aid in offsetting when cutting bevel gears and to make easier the reproduction of the settings with which a gear has been cut than is possible with the other method. This is one of many methods of bevel-gear cutting, each of which has certain advantages. When cutting gears by this method, the index head is mounted on a fixture, which is arranged so that it can be swiveled about a point on the top of the table of the milling machine.



(a)

(c)

Fig. 28

(b)

The fixture mentioned is shown in Fig. 28 (*a*). It has a **T** slot *a* cut in the top face, and three or four holes *b* are drilled in the back of the fixture central with the slot and having a diameter about equal to the width of the widest part of the slot. The location of the holes lengthwise of the fixture is not a matter of great importance. A cross-slot *c* is cut near each end of the fixture. When the fixture is in position on the milling-machine table, one of the holes *b* is placed over the pivot pin shown in Fig. 28 (*b*), which forms the center about which the fixture is turned. It may be locked in any position by **T** bolts that pass through the slots *c*. The pivot *d* has a tongue *e* that fits in one of the slots on the milling-machine table and when set, it is clamped in position by the screw and slot nut *f*. Fig. 28 (*c*) shows the left-hand end of the fixture and part of the milling-machine table on a somewhat larger scale than the other drawings of this figure. When the fixture is placed on the milling-machine table so that the **T** slot in the fixture is over and exactly parallel to one in the table, marks *g* and *h* are scratched on the end of the fixture in line with the edges of the slot in the table and other marks are made at equal distances from these and on the side of them away from the slot as shown. These marks are used when setting the fixture and index head to one side or the other of the center.

42. When setting the fixture on the milling machine, the pivot pin *d*, Fig. 29, is first put in a slot in the table *i* and fastened approximately under the center of the spindle, and it may then be brought exactly central by moving the table across the machine. The position of the table when the pin is exactly under the center of the spindle may be told in the following manner: A square is laid flat on the table so that one side touches the pin and is at right angles to the **T** slot and a mark made first on one side of the pin and then on the other. A mark is also made halfway between the other two. The last mark will be opposite the center of the pin. A point center is now placed in the milling-machine spindle and with a square placed on the central mark on the table, the table is moved until the edge of the square is opposite the point of the center in the spindle. The pin is then central and the setting should be preserved for future use by making a mark *j*, Fig. 29, on the side of the table and another mark, not shown, opposite it on the top of the saddle *k*. The fixture *l* is now put in position on the pivot pin *d* and the index head is fastened on the fixture temporarily.

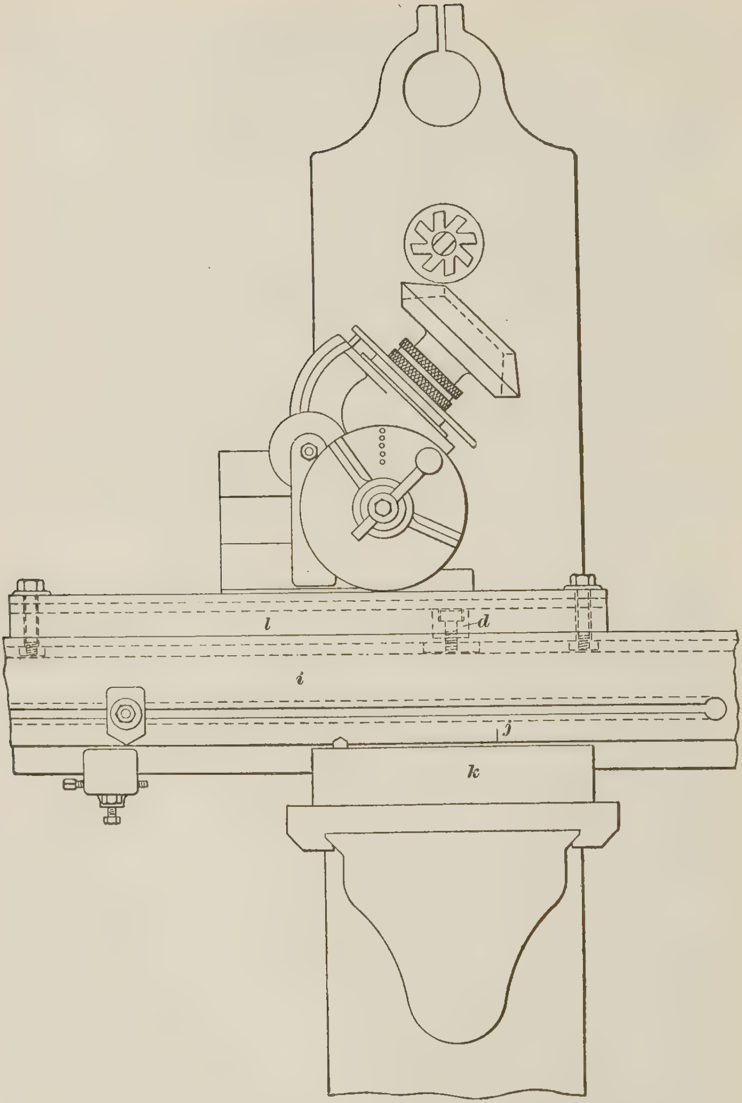


Fig. 29

43. The gear-blank is put on a mandrel in the spindle of the index head, the index head is tilted to the cutting angle, and the blank is set central with the cutter in the manner already described. The position that the index head should occupy on the fixture must be determined by trial for each gear. When the thickness of the cutter is the same as that of the space at the small end of the tooth, the index head should be set as shown in Fig. 29, so that the small end of the tooth is under the center of the milling spindle. Two slots should now be cut, indexing the gear one tooth between them. The tooth thus blocked out has the correct curve at the large end, but it is too thick. At the small end the tooth is of the correct thickness, but has not the correct curve. The thickness of the tooth at the large end may be changed by swinging the fixture *l*, with the index head attached, about the pivot *d*. The fixture is first moved in one direction and a cut taken from that side of the tooth; then it is swung an equal distance to the other side, indexed one tooth, and a cut is taken from the other side of the tooth. This process is repeated until the offset that gives the correct tooth thickness at the large end is found. The gear is then indexed twice around, cutting first with the fixture offset to one side and the second time around to the other side, thus cutting the opposite sides of the teeth. This method, as will be noted, has not changed the size or the shape of the tooth at the small end; it has, however, changed the thickness of the tooth at the large end.

44. When the cutter chosen to cut the gear is not the same width as the space at the small end of the tooth, the setting of the index head on the fixture must be changed. The index head is moved back on the fixture, which is turned about the pivot until trial cuts taken on opposite sides of the tooth give the same width at each end as the space at that end. If the index head is not set far enough back from the pivot, too much will be cut from the side of the tooth as the cutter moves along the tooth. For this reason it is better to start by setting the index head well back from the pivot so that the cut will be too light as the large end of the tooth is approached. Then swivel the fixture, as before, until the correct width of tooth is obtained at the small end. During this part of the work, no attention need be given to the large end, excepting to be sure that it is not trimmed too thin.

45. When the correct width of tooth has been obtained at the small end, the index head may be moved up on the fixture so as to get the correct thickness of tooth at the large end. To find the correct position of the index head, it may be moved a little closer to the pivot and the fixture turned about the pivot until the side of the tooth at the small end touches the cutter as it enters the slot, and a trial cut is taken first from one side of the tooth and then from the other. The thickness of the tooth is thus reduced at the large end, but is not changed at the small end. These trials should be repeated until the correct width of tooth at the large end has been obtained. The gear-tooth should then be corrected as described in Art. **40.**

PLANING PROCESS

46. Templet Planing Machine.—The principle of operation of a templet planing machine intended for planing the teeth of bevel gears is shown in diagrammatic form in Fig. 30. The gear-blank *a* is attached to the index spindle *b*, which carries an indexing wheel *c* at its other end. An arm *d* supports a longitudinally movable slide *e* that carries the pointed cutting tool *f*. The arm *d* is so mounted on a universal joint that its center of rotation *g* coincides with the axis of rotation of the gear-blank. The cutting tool is adjusted in the slide *e* in such a manner that the line of motion of its cutting point passes exactly through the center of rotation of the arm. A pin *h* is fastened to the free end of the arm, and is in contact with a templet *i*. This templet has a form that will guide the tool so as to cut the correct tooth curve.

47. The arm *d* remains stationary whenever the tool is making a cut. One side of a tooth is finished at a time by successive cuts converging toward the point *g*, which is the apex of the pitch cone. After the tool *f* has cleared the blank on its return stroke, the arm is moved slightly along the templet *i*, keeping the pin *h* in contact with the templet; the position of the arm, and hence the formation of the tooth curves, are thus determined by the templet. The form of the templet is reproduced on a smaller scale by the planing tool on the tooth operated on, and any errors existing in the templet are reduced.

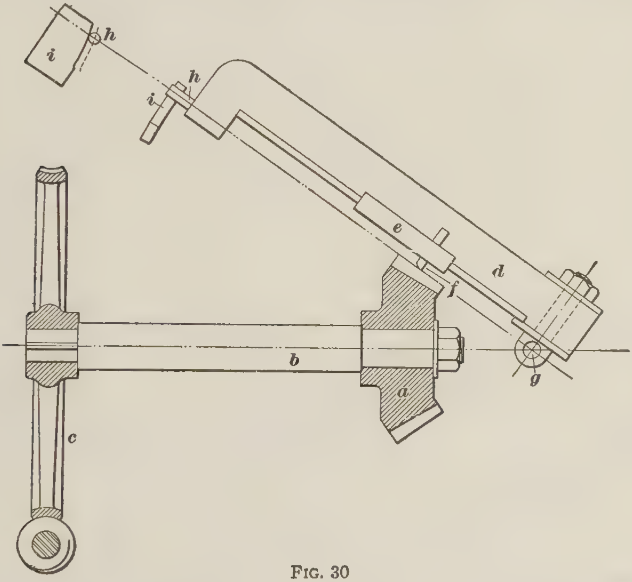


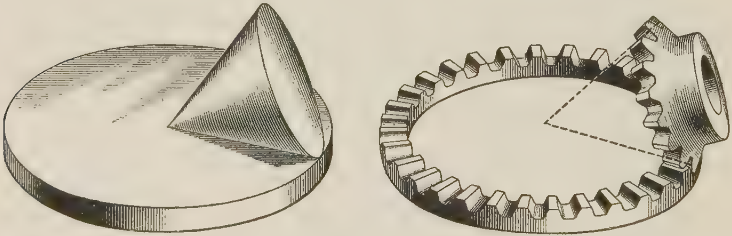
FIG. 30

The setting and operation of machines of this kind should be carried out according to instructions furnished by the maker.

48. Bevel-Gear Generating Machine.—When using the bevel-gear generating machine, the teeth are planed by means of a tool that moves in the plane of one side of a tooth on an imaginary gear on which the bevel gear that is being cut is supposed to roll. The tool then generates a correct tooth outline on the bevel gear.

If a cone rolls on a flat plate without slipping, it moves in a circle of which the point of the cone is the center, as is shown in Fig. 31 (*a*). If, now, the surface of the flat plate is used as a pitch surface on which to construct teeth, a form of bevel gear, called a *crown gear*, is obtained. A bevel gear, the point of whose pitch cone is at the center of the crown gear, will roll on the crown gear with the same motion that the cone had when rolling on the flat plate. Such a crown gear and bevel gear are shown in Fig. 31 (*b*).

49. Suppose, now, that to the bevel-gear blank is given the same motion that it would have if it rolled on a crown gear, and that a cutting tool is moved with its cutting edge in the plane of one side of a tooth of the crown gear, a tooth outline will be generated on the blank. Fig. 32 shows diagrammatically the movement of the cutting tool when this principle is applied. The cutting edge moves in line with one face of the crown gear-tooth, as shown at *a*, where the shaded portion represents the tool. The tool moves in a straight line toward the center *o* of the crown gear as is indicated at *b*. In the side view, *o c* is the vertical line passing through the center of the crown gear and *o d* is the plane of the pitch surface; *o* is therefore the center toward which all tooth lines converge. Hence, the point of the tool *e* must move along the line *o f*, which is then the movement of the generating tool.


(*a*) FIG. 31 (*b*)

In the mechanism illustrated diagrammatically in Fig. 33, this principle is used. The gear to be cut is shown at *a* fastened to a master gear *b* whose pitch cone coincides with the pitch cone of gear *a*. When the master gear rolls on the crown gear *c*, the gear to be cut will receive the same motion that it would have if it rolled on a crown gear having teeth that extend from the crown gear *c* to the center. If, now, the cutting tool has the motion described in connection with Fig. 32, correct tooth outlines will be generated on gear *a*.

50. Machines employing this method of generating bevel-gear teeth use only segments of the gears *b* and *c*, since the gear that is being cut needs to rotate only far enough to complete one tooth. Suitable arrangements are also made so that the gear that is being cut may be indexed relative to the master gear after each tooth outline has been generated. Some machines are provided with two tools so arranged that while one tool is generating one side of the tooth outline the other tool is generating the other side of the same tooth: thus, one complete tooth outline is cut at each indexing of

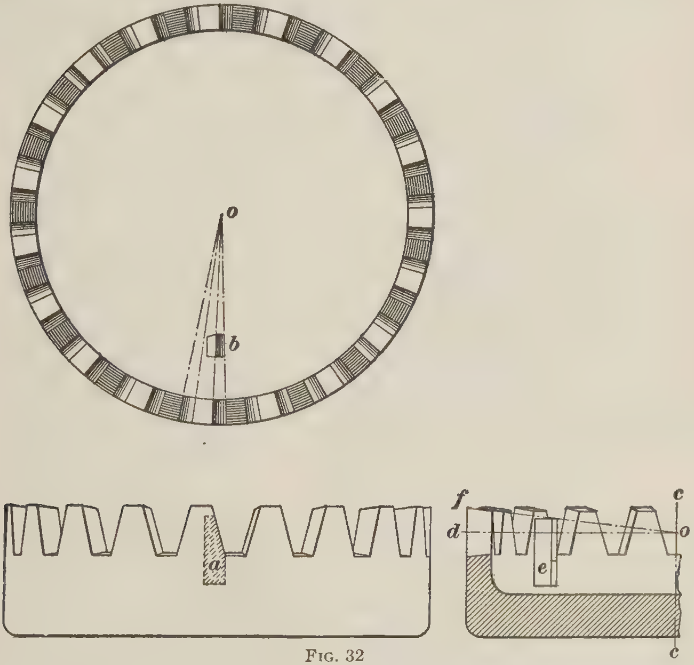


Fig. 32

the gear. Sometimes, however, the tools cut simultaneously the outlines of the tooth curves on the opposite side of a space.

51. Inspection.—Gears should be inspected to determine whether or not they are cut accurately in the following respects: that the teeth are cut at the correct angle to the face of the gear, that the size of the teeth is correct, and that the teeth are of the correct shape. The teeth of spur gears should be square with the face of the gear, those of helical gears must be at an angle that is always specified, and the teeth of bevel gears must converge toward the point of the pitch cone. In order to determine whether the teeth are at the correct angle to its face, the gear to be tested should be mounted with one that is known to be true on a pair of studs that are in the same position regarding each other as the shafts on which the gears are to be mounted. The gears should then be run together and the bearing marks between the teeth noted. In order that the bearing marks may be more easily seen, the teeth of one of the gears may be coated with red lead or with copper, which will be rubbed off wherever the teeth come in contact. If the teeth on the gear that is

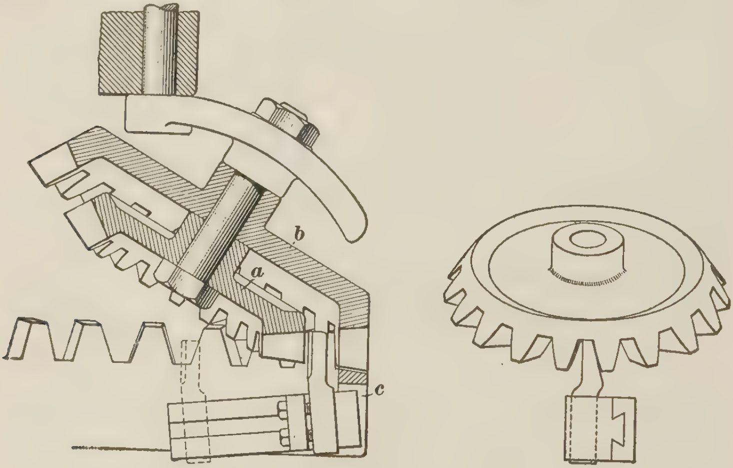


FIG. 33

being tested are not at the correct angle to the face of the gear, the red lead will be removed from one side of the tooth at one face of the gear and from the other side at the other face.

52. The foregoing may also be used as a preliminary test to determine the accuracy of the tooth size. When rolling the gears together, the tightness or the freedom of their action may be noted. If the action is too tight or too loose, but equally tight or loose all the way around, the teeth are too thick or too thin. If the gears run tight or loose in spots, some of the teeth are too thick or too thin; the nature of the inaccuracy and the position of the inaccurate teeth may be found by means of the gear-tooth caliper.

53. The accuracy of the tooth shape may be tested by coating the teeth of one gear with red lead or copper, and rolling the gears together. If the teeth are of the correct shape, the lead or copper coating will be rubbed off where the gears come in contact. Experienced men can test the accuracy of the tooth shape of spur or helical gears by rolling them together in their hands. This test, however, does not apply either to helical gears having axes that are not parallel, or to involute gears of the $14\frac{1}{2}°$ system having a small number of teeth.

54. An excellent general test of gears is to run them under load at the normal distance between centers. Inaccurate gears will become apparent by the noise they make. In this test, is should be noted that if the gears are not rigidly mounted, the effect will be the same as though they were not well cut. Another condition that may prove misleading is noise that is due to the tendency of some other part of the machine to act as a sounding board. If the gears are noisy when this test is applied, the cause of the noise may be found by applying the foregoing tests.

STUB-TOOTHED GEARS

55. Gear-teeth made shorter than those in the standard systems, are called **stub teeth.** The width of the stub tooth is the same as that for a tooth in the standard system; but the depth is proportioned according to a finer pitch of the same system. The pitch of a stub-toothed gear is therefore designated by a fractional number. The numerator of the pitch fraction gives the pitch of the standard system from which the width of the tooth has been proportioned and the denominator gives the pitch of the same system from which the depth of the tooth has been proportioned. For example, the teeth of a $\frac{4}{5}$-pitch gear are of the same thickness as the teeth of a 4-pitch standard gear and their depth is the same as that of a 5-pitch gear of the same system.

TABLE VII

TOOTH PROPORTIONS IN THE STUB-TOOTH SYSTEM

Diametral Pitch Fraction	Tooth Thickness Inch	Addendum	Whole Depth of Tooth
$\frac{4}{5}$	.3927	.2000	.4500
$\frac{5}{7}$	.3142	.1429	.3214
$\frac{6}{8}$	.2618	.1250	.2812
$\frac{7}{9}$	.2244	.1111	.2500
$\frac{8}{10}$	.1963	.1000	.2250
$\frac{9}{11}$	.1745	.0909	.2045
$\frac{10}{12}$	.1571	.0833	.1875
$\frac{12}{14}$	.1309	.0714	.1607

56. Stub-toothed gears are usually cut in the gear-shaper described in Art. **18,** though there is no reason why other methods of cutting should not be used. Table VII gives the pitch fractions for which cutters are made and the proportions of the teeth produced by each. Each cutter will cut gears having any number of teeth of its own pitch.

GRINDING

(PART 1)

GRINDING WHEELS

GRINDING-WHEEL MATERIALS

1. The term **grinding**, as used in connection with modern shop work, is understood to mean the removal of stock by means of a stone or a wheel composed of abrasive material. The cutting grains in a grinding wheel or stone are ordinarily spoken of as **abrasives**; thus, emery, alundum, carborundum, etc. are abrasive materials. The object of grinding is the removal of stock from a piece that is oversize or has rough imperfections, the accurate sizing of a piece, or the production of a very smooth surface. Grinding is done by angular grains of some hard substance, which are held in place by being cemented with some bonding material, or are bedded in a softer substance, as for example, a lead lap. The modern grinding wheel reduces the size of the work by cutting off chips instead of rubbing off a powder; this may be proved by examining the chips through a microscope.

Most grinding materials are used in the form of wheels, and may be divided into two classes: *grindstones* and *manufactured grinding wheels*, the latter including emery, corundum, alundum, crystolon, carborundum, aloxite, and adamite wheels. Oilstones, polishing wheels, buffing wheels, and laps are other applications of grinding materials.

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GRINDSTONES

2. Composition of Grindstones.—Grindstones are simply natural sandstones of suitable texture for grinding operations. The cutting material is oxide of silica, commonly known as *quartz sand*. The individual grains, in order that they may be in proper condition for cutting, must be sharp and angular. As found in nature, they are bound together either by a lime cement, or by a silicate bond. This bond must be of such nature and strength that when the grains of sand become dull, the friction of grinding will tear them out and thus uncover fresh, sharp grains for the work.

3. Many of the best grindstones used in the United States come from Berea, Ohio; Huron, Michigan; and from Grindstone Island, Nova Scotia. From these localities several grades of stones are secured; the Nova Scotia stones are coarse, medium, and fine. Most of the Berea stones are rather coarse. A few foreign stones are also used in the United States, most of which are known as Liverpool stones, which vary in quality from medium to fine.

4. Action of Water on Grindstones.—As grindstones cut more freely when wet, they are generally used with water. The water softens the bond, carries off the heat resulting from the friction between the stone and the tool, and washes away the particles of the stone and steel that are dislodged by the grinding, and that, if not carried away, would tend to fill up the small spaces between the grains of the grindstone, and thus reduce the stone's cutting ability.

Three important points in this connection should be noted. Grindstones should not be left standing with only one side in water, as the water will soften the bond of the wet side and cause it to be worn away faster than the other when the stone is again used. When one side of the stone is left heavy with water, it is thrown out of balance, and there is danger of bursting. If grindstones are used in exposed places during cold weather, the water will freeze and crack the stone, which will fly in pieces when started.

5. Grade of Stone Required for Thin Work.—For grinding such pieces as mowing-machine knives, or other pieces having sharp thin edges, the stone must cut freely in order not to heat the work and draw the temper. The stone must therefore be soft enough to wear away with such rapidity as to keep the cutting particles at the grindstone surface always sharp.

6. Tool Rests for Grindstones.—For general tool grinding, a rest is commonly used. A temporary or movable rest, such as a block of wood, is regarded by some mechanics as being the most desirable, because in case the tool should catch, the rest would be readily broken, and the damage to the stone or to the operator would be less than if a solid, permanent rest were used.

7. Grindstone Mountings.—In mounting the stone, it is desirable to use iron flanges, about one-third the diameter of the stone. These flanges are so hollowed on the inside as to only bear upon the stone for 1 inch or more near their peripheries. The stone is frequently mounted without flanges, in which case the stone has a square hole in its center, and the shaft, which is also square where it passes through this hole, is surrounded by a bushing of wood or Babbitt. Fig. 1 shows a grindstone mounted upon a frame that has a trough for water and also a truing device attached to it.

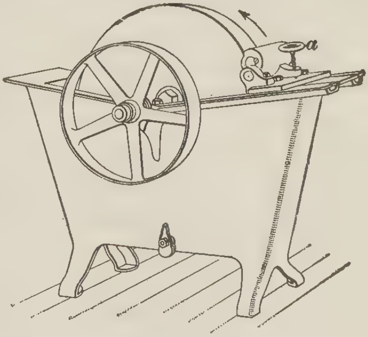


FIG. 1

8. Automatic Truing Device.—The truing device shown on the frame in Fig. 1 works automatically, and can be applied while the grindstone is in use, and removed when the stone has been trued. It is applied to the face of the stone that moves upwards. By turning the hand wheel *a*, a threaded roll is brought in contact with the stone and kept there until the stone is trued, the water meanwhile being left in the trough. When the screw threads become dull, they can be recut. Fig. 2 shows the truing device removed from the stone, the threaded roll being shown at *b*.

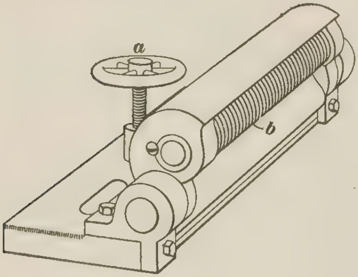


Fig. 2

9. Truing by Hand. All grindstones work out of true, and in the absence of an automatic truing device, the stone is sometimes trued by the use of an old file and a piece of gas pipe, or by using a piece of gas pipe alone. If the stone is badly out of true, the surface should be turned off with the tang of an old file held firmly on a rest against the face of the stone, as shown in Fig. 3 (*a*). This will remove the high parts of the stone quickly, but will leave the surface quite rough. A smooth surface may then be produced by truing the face with a piece of gas pipe, the size commonly used being $\frac{3}{8}$-inch to $\frac{3}{4}$-inch pipe. The pipe is held on the rest, but rolled across the face of the stone as shown in Fig. 3 (*b*). In both cases, the stone should revolve in the direction indicated by the arrow.

10. Speed Used in Grinding Tools.—For tool grinding, the grindstones are run at much less than their maximum speed. The stone may be run at the highest speed at which the water will not be thrown from its face by the centrifugal force. Table I shows the maximum safe speeds given by some authorities, and should only be exceeded when a very hard, strong stone is used, and then only when the stone is well

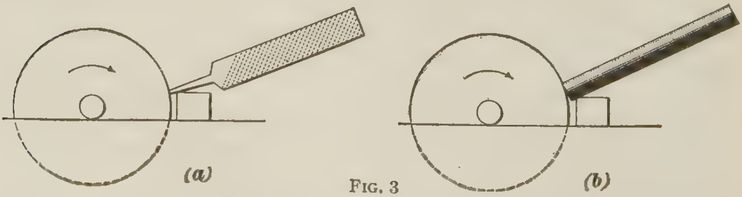

(a) (b)

Fig. 3

TABLE I

TABLE OF MAXIMUM SPEEDS

Diameter of Stone	Revolutions per Minute	Diameter of Stone	Revolutions per Minute
8 feet	135	5 feet	216
7 feet 6 inches	144	4 feet 6 inches	240
7 feet	154	4 feet	270
6 feet 6 inches	166	3 feet 6 inches	308
6 feet	180	3 feet	396
5 feet 6 inches	196		

mounted with strong flanges, and is so protected by a hood that there would be no danger from bursting. The number of revolutions given correspond to a periphery speed of nearly 3,400 feet per minute.

MANUFACTURED GRINDING WHEELS

11. Emery.—Manufactured grinding wheels are composed of irregular hard grains, which do the cutting, and a bond, or substance which holds the irregular grains together. Emery, one of the best known cutting grains, is a mineral mined principally in Naxos, Greece; Smyrna, Turkey; and Chester, Massachusetts. It is composed of crystalline aluminum oxide, from which it derives its cutting properties, and an oxide of iron. Chester emery has about 55 per cent. of crystalline aluminum oxide, Turkish emery 57 per cent., and Naxos emery 63 per cent. All natural abrasives vary more or less in quality, which is a great detriment to their use for grinding wheels. Emery adapts itself very well to some grinding operations, in that the grains are very rough, and for this reason can be bonded together very hard, making a wheel with great durability or life.

12. Corundum.—Corundum is a very pure form of emery. The quantity of corundum is limited, and, like other abrasives, its quality varies. This material is now principally obtained from Canada, and is then known as Canadian corundum. A good grade will contain as high as 90 per cent. of crystalline aluminum oxide. Corundum is very well adapted to grinding highly tempered materials such as tools that require a cool cutting wheel; that is, a wheel which will heat the work comparatively little.

13. Alundum, Aloxite, and Adamite.—Alundum, aloxite, and adamite are the trade names used for artificial corundum. Alundum is a product of the electric furnace and is made from bauxite, a hydrate of aluminum. This bauxite is heated to a red heat to drive off the combined water, and after being mixed with certain chemicals, which will remove the impurities, is ready to be introduced into the electric furnace. The fused mass from the furnace is referred to as a *pig*, and takes from 2 to 3 days to cool. When it has reached the proper temperature it is broken up into pieces about the size of a man's head and shipped to the grinding-wheel factory to be made into wheels. Aloxite and adamite are made in a similar way. These three abrasives are the most efficient for all kinds of steel grinding. Owing to the method of manufacture, they can be made with different properties, or different tempers. The condition of the abrasive as regards hardness and brittleness is called **temper.** For heavy rough work, an abrasive of great toughness is demanded; whereas, for the internal grinding of hardened tool steel in which the cutting points dull rapidly, a more or less brittle, sharp abrasive is required. For the former work an abrasive of tough temper would be used; for the latter, an abrasive of brittle temper.

14. Carborundum and Crystolon.—Like alundum and aloxite, carborundum and crystolon are carbides of silicon and are products of the electric furnace. They are made by surrounding a small core or cylinder of pure carbon with a mass of coke and sand to which a little salt and sawdust is added. A powerful electric current is then passed for a period of 36 hours, through the carbon core, which, by its resistance to the current, becomes heated to a temperature of about 7,000° F., and this heat is communicated to the coke and sand surrounding it. At the high temperature thus obtained, the carbon and silicon unite and crystallize, and when the furnace is cooled and the core uncovered, it is found to be surrounded by a ring of brilliantly colored crystals of carborundum or crystolon. The crystals are now removed and broken into individual grains. Carborundum and crystolon are extremely hard and sharp, but brittle. These characteristics make them the most efficient abrasives known on cast iron, brass, bronze, and other soft alloys.

SELECTION OF WHEELS

15. Shapes of Wheels.—Grinding wheels are made in various shapes, some of those most commonly used being shown in Fig. 4. Wheels having the shape of a flat circular disk with a small central hole, as the one shown in (*a*), are used for external grinding. The wheels most commonly employed on cylindrical grinding machines have large central holes, as shown in (*b*). Such wheels are mounted on special arbors or upon bushings on an ordinary arbor. Cupped wheels like the one shown in (*c*) are usually mounted directly on the spindle and are used for surface grinding, the face *a* being used for this purpose. Sometimes these wheels are made without the shoulder for attaching them to a spindle, in which case they are simply plain cylinders. For example, if the wheel shown in (*b*) had a face several inches wide, it could be employed for surface

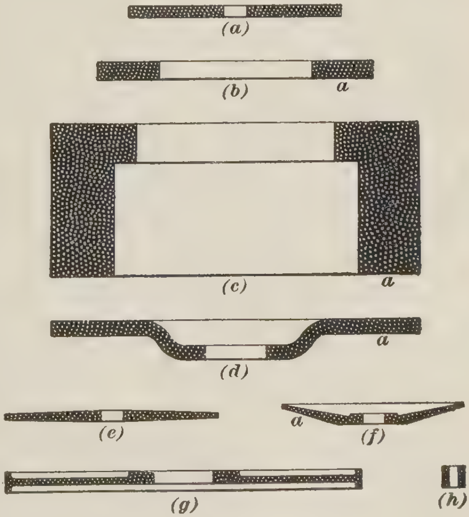


FIG. 4

grinding by mounting it in a chuck, the work being ground by the face *a*. A wheel that has the shape shown in (*d*) is used for grinding close to the shoulder of work that has a very large flat shoulder; the shape of the wheel permits this, since it allows the face of the nut that fastens the wheels to the spindle to come below the face *a* of the wheel. The grinding is done by the periphery of the wheel.

16. A narrow conical wheel, like the one shown in Fig. 4 (*e*), is much used for grinding the clearance of reamers, milling cutters, and similar cutting tools in cutter-grinding machines, in which case the wheel is used dry. The narrow face of this wheel will not grind as fast as a wide-faced wheel, neither will it generate as much heat, which fact makes the narrow-faced wheel more suitable for dry cutter grinding than the wide-faced wheel. A saucer-shaped wheel like that shown in (*f*) is much used for sharpening the teeth of narrow formed cutters, as, for instance, gear-cutters; the grinding is usually done by the inside face, the conical surface *a* just clearing the back of the next tooth of the cutter. A recessed wheel of the form illustrated in (*g*) is used for grinding a square shoulder on cylindrical work, and like the cupped wheel shown in (*c*), it can be used for surface grinding on light work, such as the measuring surfaces of caliper gauges. The shape shown in (*h*) is used for grinding small holes.

17. Grain of Wheels.—By the grain of a wheel is meant the size of the particles of the abrasive material. After coming from the mine or the electric furnace, the abrasive is crushed, washed, dried, and screened. The screening consists in passing the material over a set of screens, which are shaken, and in this way the different sizes are separated. No. 24, for instance, is the size of material which has passed through a screen having twenty-four meshes to the linear inch, but which was too large to pass through a screen which had thirty meshes to the linear inch. Grain sizes vary from 8 to 220. Material finer than this is referred to as *flour*. F is the grade of flour that is a little finer than No. 220; FF is finer than F; and FFF is still finer. Abrasive powders finer than FFF are graded by the length of time they will remain suspended in water; for example, dust which will remain suspended in water 1 minute is known as 1-minute abrasive, and dust which will remain suspended 15 minutes, as 15-minute abrasive.

18. Grade of Wheels.—Grade is the term used to designate the hardness or softness of the wheel; that is, the strength with which the cutting particles are cemented, or held together by the bond. Hard wheels have the cutting particles very strongly cemented and a cutting particle could be only with difficulty torn away from the rest of the wheel. All grinding wheels must be graded very carefully, as the success or failure of most grinding operations depends on the grade of the wheel used. Grading is done by comparing the wheels being made against those of standard qualities.

Wheels are graded as *very soft*, *soft*, *medium soft*, *medium*, *medium hard*, *hard*, and *very hard*. All grinding-wheel manufacturers use the same method of indicating the size of grain in a wheel, namely, the number of meshes in the screen through which it has passed; but nearly every concern uses a different method of denoting the grade of a wheel. For instance, the Norton Company uses the alphabetical method for vitrified and silicate wheels, which is perhaps the simplest. The first letters of the alphabet are used to designate soft wheels and the last letters hard wheels. However, the grade of elastic wheels is indicated by numbers and varies from 0, which is soft, to 6, which is hard. The Carborundum Company also employs letters to denote the grade, but use just the reverse of the Norton method, the last letters in the alphabet denoting the wheels of soft grade.

19. Bonding of Wheels.—Grinding wheels are made by a number of processes, among which may be mentioned: *vitrified*, *silicate*, *elastic*, *vulcanite*, and *celluloid*. About 85 per cent. of the grinding wheels used are made by the **vitrified process.** The bond, or the cement which holds the cutting particles together in vitrified wheels, is made up of different kinds of clays and fluxes which are mixed together according to definite formulas. The abrasive, bond, and water are mixed together, and molded into wheel shapes. The wheels are then dried and burned in a kiln, producing the vitrified wheel. Wheels larger than 36 inches in diameter are usually made by the vitrified process.

20. The bond used in the **silicate process** is a silicate of soda, or water glass. This bond and the abrasive are mixed together, and formed into wheel shapes, which are baked for a day or so. Wheels are more readily made by the silicate than by the vitrified process. Silicate wheels are not, however, as free cutting as vitrified wheels, and can be made extremely large. Silicate wheels are well adapted to wet tool grinding.

21. In the **elastic process,** shellac is used for a bond. The abrasive and the shellac are mixed together and heated till the shellac becomes sticky, thus coating each grain of abrasive with shellac. After cooling, the mixture is placed in molds which give the desired shape of the wheel, heated, put under hydraulic pressure, allowed to cool, taken out of the mold, and baked at a temperature of 350° F. for 1 day or longer. Extremely thin wheels can be made by this process, since an elastic wheel is stronger than a vitrified or silicate wheel. Thin vitrified or silicate wheels would be liable to break. For free cutting, elastic wheels have not been found satisfactory.

22. In the **vulcanite** and **celluloid processes,** rubber and celluloid, respectively, are used for bonds. The abrasive and the bond are thoroughly mixed, rolled into sheets of the thickness required for the wheels, and cut into the desired wheel shapes. The vulcanite wheels are now subjected to a vulcanizing process and the celluloid wheels are allowed to season for several months. Extremely thin, hard, but expensive wheels can be made by these processes.

23. Finishing of Wheels.—As they come from the baking or burning process the wheels are somewhat oversize and very rough, and must be finished to the dimensions ordered. Smoothing of the sides by bringing a dressing tool against them is the first operation. A lead bushing .005 inch larger than the grinding-wheel spindle on which the wheel will be used is provided. This bushing will slide on the spindle easily without being loose.

24. As the wheel must run true when it is in use, it must be faced. The **facing** operation is done after the wheel has been bushed. This is accomplished by mounting the wheel on a true-running machine and truing up the face by means of a dresser. The dresser shown in Fig. 5 consists of a long handle *a* terminating in a fork; a small spindle is mounted in this fork and on this spindle are loosely mounted three or four very hard metal disks *b*, called cutters, which are free to revolve on the spindle. When the dresser is brought in contact with the wheel, the cutters being loose on the spindle, roll around with the wheel and knock off the rough grains; in this way, the wheel is dressed cylindrically. The projection *c* serves as a support for the tool when in use. The truing tool may be used either as part of an automatic machine or as a hand tool. The manufacturer, in preparing wheels for the market, frequently employs the automatic machine. The user of wheels should have a hand dresser to true the wheels whenever they wear a little out of round.

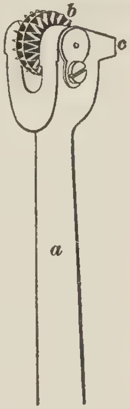


FIG. 5

25. Large wheels and wheels to be used on delicate machines must be balanced. **Balancing** is accomplished by mounting the wheel on an arbor and allowing it to revolve slowly on parallel ways. After the wheel has come to rest, the heavy part is naturally downwards. The amount the wheel is out of balance is then corrected by attaching small weights to the rim of the wheel on the light side. Should the weight necessary to balance the wheel be enough to cause trouble in grinding by vibration, the wheel is balanced by chiseling out some of its structure, right next to the bushing, on the light side and filling this space with lead. Sometimes it will be found that after a wheel has worn down to a small diameter, it will be heavy on the lead-balanced side. It is then necessary to chisel out some of the lead to bring the wheel back in balance. The lack of balancing is often the cause of poor work, particularly when the wheels are used on light machines.

26. The wheels are now ready for **testing.** Wheels larger than 5 inches in diameter are generally tested immediately before shipment at 9,000 surface feet a minute. As the usual operating speed is about 5,000 feet a minute, and as the stress present in a revolving body is proportionate to the square of the speed, this testing speed produces about three and one-half times the stress present at ordinary working speeds. Wheels smaller than 5 inches in diameter are not tested, since it would be practically impossible for the user to run them at a dangerous speed.

27. Speed of Wheels.—Most grinding wheels operate at from 4,000 to 6,000 surface feet per minute. Wheels on rigidly designed cylindrical grinding machines are sometimes operated as high as 7,000 surface feet per minute. Wheels for cutter and reamer grinding and those used on bench and floor grinders, are operated at about 5,000 surface feet per minute. Cylinder and cup wheels used on vertical spindle surface-grinding machines are run about 4,000 surface feet per minute. Table II gives the number of revolutions per minute required to obtain different surface speeds for wheels of various diameters.

28. Contact of Work and Wheel.—The word *contact* is used to designate the area of the wheel and work which are in contact when grinding. If grinding is done on a thin edge, the contact is narrow; if a flat surface or the inside of a hole is being ground, the contact is broad. A harder wheel must be used for a narrow than for a broad contact, because more pressure is brought to bear on the cutting particles on the narrow contact, thus tending to tear them loose. Each cutting particle is in touch with the work longer and therefore becomes duller, on broad contact, and must be released from the wheel after it has passed its point of usefulness, so that the sharp points from underneath may come to the surface and do the cutting.

29. Effect of Varying Wheel Speed.—The faster a wheel runs, the more it will act like a wheel of harder grade; and, on the other hand, the slower it runs, the softer it will act. Therefore, if it is found that the wheel used for a particular operation is too hard, better results can be obtained by reducing the wheel speed. For cylindrical grinding 6,000 surface feet per minute has been found the most satisfactory

TABLE II

SPEEDS OF GRINDING WHEELS

Diameter Inches	Surface Speed, in Feet per Minute						
	1,000	2,000	3,000	4,000	5,000	6,000	7,000
	Revolutions per Minute						
1	3,820	7,639	11,459	15,279	19,099	22,918	26,738
2	1,910	3,820	5,730	7,639	9,549	11,459	13,369
3	1,273	2,546	3,820	5,093	6,366	7,639	8,913
4	955	1,910	2,865	3,820	4,775	5,730	6,684
5	764	1,528	2,292	3,056	3,820	4,584	5,348
6	637	1,273	1,910	2,546	3,183	3,820	4,456
7	546	1,091	1,637	2,183	2,728	3,274	3,820
8	477	955	1,432	1,910	2,387	2,865	3,342
10	382	764	1,146	1,528	1,910	2,292	2,674
12	318	637	955	1,273	1,592	1,910	2,228
14	273	546	819	1,091	1,364	1,637	1,910
16	239	477	716	955	1,194	1,432	1,671
18	212	424	637	849	1,061	1,273	1,485
20	191	382	573	764	955	1,146	1,337
22	174	347	521	694	868	1,042	1,215
24	159	318	477	637	796	955	1,114
30	127	255	382	509	637	764	891
36	106	212	318	424	531	637	743

speed, although some grinding-machine makers recommend a speed as high as 7,000 surface feet per minute. If satisfactory results are not being obtained in cylindrical grinding, by either changing the work speed, the depth of cut, or the table traverse, they can usually be obtained by changing the grinding-wheel speed.

30. The complaint is often heard that wheels appear softer near the center than they did when full size. This condition is usually due to the fact that the wheel is run at the same number of revolutions per minute as when it was large, and since the diameter has become smaller, the surface speed is slower. It is a law of grinding that the slower the speed of a grinding wheel, the softer it acts; so if the surface speed is kept constant—that is, if the revolutions per minute are increased in proportion as the diameter of the wheel decreases—wheels will not act softer near the center than they do when full size. Another point is that the contact surface is smaller with a small cylindrical or conical wheel than with a large one, and since narrow contact brings more pressure to bear on each individual cutting grain, the wheel wears faster.

31. Glazing of Wheels.—A wheel is said to be glazed when the cutting particles have been dulled to such an extent that the wheel no longer cuts freely and excessive pressure is necessary to keep up the required production. Glazing is caused by the wheel either being too hard, or being run at too high a speed. If, after the speed has been reduced and the wheel dressed, glazing still occurs, the wheel is too hard for the work and a softer one should be procured. The use of a glazed wheel is usually accompanied by such difficulties as burning the work, chatter marks, and requiring a longer time than necessary to complete the operation.

32. Loading of Wheels.—The filling up of the spaces between the cutting particles with the material being cut is called *loading*. It is also referred to as *filling* and *gumming*. For cylindrical grinding work, the best remedy for loading is usually the use of a softer wheel. Another remedy is to increase the wheel speed, after the wheel has been properly dressed and is free from the loaded material. For grinding very soft material, such as aluminum, loading has often been overcome by treating the wheel with a heavy grease, or tallow. This treatment lubricates the spaces between the cutting particles and also fills them up with grease, thus preventing the material being ground from sticking.

33. Selection of Abrasive.—Very tough high-carbon steels are difficult to grind. They require a great deal of power and very soon dull the cutting points of a grinding wheel. In this instance it is necessary to use a soft wheel. Low-carbon steels and wrought iron are much softer than high-carbon steels; and the cutting particles of the wheels used to grind them are not dulled as rapidly, are permitted to penetrate deeper, and are consequently loosened sooner. A hard wheel, which has its cutting particles firmly cemented, can, therefore, be used to withstand the resistance of a deep cut. Alundum and similar abrasives are considered most efficient on materials of high tensile strength, while crystolon and carborundum are better adapted to materials of low tensile strength. An alundum, aloxite, or adamite wheel should be used on steel and a carborundum or crystolon wheel on cast iron, brass, bronzes, and other alloys. Carborundum and crystolon, while very hard and sharp, are weak and cannot stand up under the resistance offered when grinding steel. Alundum, aloxite, and adamite are tough, but dull more rapidly; hence, a carborundum or crystolon wheel will remain sharp and do better work on soft materials than an alundum, aloxite, or adamite wheel.

34. The success or failure of a grinding operation depends almost entirely on the care exercised in the selection of the grain and grade of the wheel. A good many of the difficulties experienced in grinding can be eliminated. The kind of machine, its condition, the speed of the wheel, if cylindrical or internal grinding, the speed of the work, and the kind of material that is being ground, are all very important and must be considered when selecting a wheel for a particular operation.

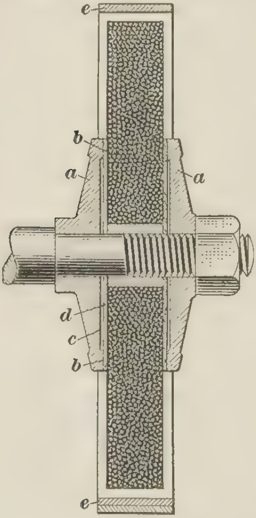


Fig. 6

35. Wheel Mountings and Hoods.—The mounting of a grinding wheel is a very important item concerning the safety of the operator. In Fig. 6, *a* are the flanges, *b* the bearing between the wheel and flanges, *c* a clearance space, and *d* a compressible washer of blotting paper. Good practice demands that flanges at least one-half the diameter of the wheel, and relieved so that they only bear on a flat ring surface near their outer edges, be used. Compressible washers of rubber or blotting paper should be employed between the wheel and the flanges to take up any imperfections in either wheel or flange, so as to distribute the pressure uniformly when the nut is tightened. The inner flange should be keyed or shrunk on the spindle; otherwise, the nut is liable to crawl and the wheel be broken from excessive tightening of the flanges.

To protect the workman from the flying pieces, should the wheel break, a substantial hood *e*, Fig. 6, is usually provided. This hood completely encloses the wheel except for the small opening in the front to permit the work being brought against the wheel.

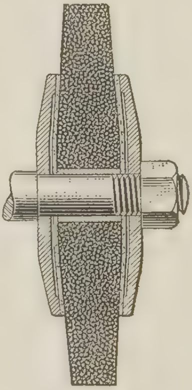


Fig. 7

36. Protection Flanges.—In Fig. 7 is shown a type of flange known as the protection flange, in which, if a wheel should break, the pieces will be retained and injury to the workman will thus be prevented. These flanges are so designed that the hub of the wheel is thicker than the opening between the flanges. These flanges, however, offer no protection from pieces which break off outside of them, and therefore wherever possible, protection hoods, which offer the best protection to the operator, should be used.

OILSTONES, POLISHING, AND BUFFING

OILSTONES

37. An **oilstone** is a smooth, fine-grained stone which is used, when moistened with oil, to sharpen edged tools. Oilstones are of two kinds, *natural* and *manufactured.*

38. Natural Oilstones.—The natural oilstones are rubbed to the required size on what is termed a rubbing bed. Rubbing beds revolve in a horizontal plane; and sand, or some other abrasive, and water are allowed to flow on the beds near the center. The revolving of the bed gradually carries the abrasive and water to the edge of the bed. The oilstones are held stationary while the bed revolves under them and they are usually weighted to hasten the rubbing.

39. The two principal varieties of natural oilstones in use are the *Arkansas* and the *Washita.* The **Arkansas oilstone** is very hard, and is used where a keen cutting edge is desired. The hardness of the stone permits the hardest of steel tools to be sharpened to fine points without grooving the stone. These stones are furnished in two grades, hard and soft. The hard stones are finer in texture than the soft stones and necessarily cut slower; but, owing to their fineness of grain, they are capable of producing a very sharp edge. The soft stone cuts faster, because it is coarser and softer, and is very well adapted for sharpening woodworking tools.

The **Washita oilstone** is composed of silica, but is more porous in texture than the Arkansas. It is used mostly for sharpening carpenters' tools.

40. Manufactured Oilstones.—Practically all manufactured oilstones are made by the vitrified process and the account given of the manufacture of vitrified wheels applies to oilstones as well. Like manufactured grinding wheels, manufactured oilstones are rough and somewhat warped after the burning, and they must be smoothed up and brought to size. This finishing is done on rubbing beds, the nature of the operation being similar to the rubbing of natural oilstones.

41. There are three principal brands of manufactured oilstones; namely, *india*, *crystolon*, and *carborundum*. **India** is the trade name for the stone which is made of alundum. Owing to the fact that alundum can be made with varying strength of grain and character of fracture, the india stone lends itself to a greater variety of work than any other oilstone. Since it is a manufactured stone, it is uniform in texture. This stone, being made in a great variety of shapes, grains, and grades, is adapted to practically every sharpening operation. A very convenient form of stone is the combination stone, which is coarse on one side and fine on the other. Both the crystolon and india stones are oil filled, which insures an oily sharpening surface with the use of only a small quantity of oil. With stones which are not oil filled, a larger quantity of oil will be found necessary to lubricate the surface, as most of the oil penetrates the stone.

42. Very hard and sharp oilstones are also made of **carborundum** and **crystolon.** These stones cut very rapidly, but do not hold their shape as well as the india stones; they are very well adapted for sharpening carpenters', cabinetmakers', and general woodworking tools. Like the india stone, they are made in many sizes and in great varieties of grains and grades, and since they are a manufactured product, are uniform in composition. Combination stones, or stones that are coarse on one side and fine on the other, are also made of carborundum and crystolon.

POLISHING

43. Polishing differs from grinding in that it is not done to change the size and shape of the work, but simply to create a bright or smooth surface.

44. Polishing Wheels.—Polishing wheels are usually made by covering the periphery of wooden wheels with leather, and gluing to the leather a coating of abrasive. After giving the wheel a thick coating of hot glue, and before the glue becomes dry, the wheel is rolled in a trough containing the loose abrasive which has been previously heated. The wheels are hung in a warm room for a day before using, and are trued by holding an oilstone or other hard substance against them while running, thus leveling the rough or projecting places.

Polishing wheels should be kept true and in running balance. If a wheel is not true, it wastes abrasive, glue, and time, and will not do good work. Only the best glue and the abrasive which produces the best work should be used. The glue pots should be kept clean.

45. Abrasives Used on Polishing Wheels.—Emery is perhaps the most common abrasive used, although this is being displaced by alundum, crystolon, aloxite, and carborundum. The manufactured abrasives are sometimes found to be anywhere from two to six times more efficient than emery. A good quality of corundum is considered a very efficient abrasive; but its quality varies, and it is usually not satisfactory. For roughing work, the sizes of the grains used vary from No. 20 to No. 80. For dry fining—that is, polishing without the use of a lubricant—Nos. 90 to 120 are used, and for the finishing cut, Nos. 150 to FFF are employed. A better finish can be obtained if a little oil, beeswax, or tallow is used on the finishing wheel.

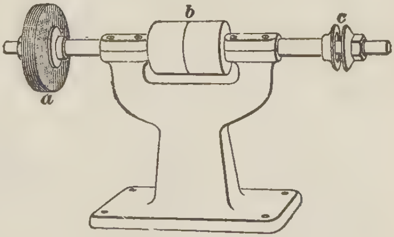


FIG. 8

46. Polishing Belts.—Flat and curved surfaces are polished on the periphery of wheels and more irregular objects are polished by holding and turning them against leather belts covered with abrasive and running over pulleys, these belts being wide or narrow, tight or loose, according to the shape of the work. When polishing, the work is held in the hand and moved in such a manner that the desired finish is produced. Much practice is required to polish fine work, as it is a matter of skill and touch on the part of the workmen.

47. Polishing-Wheel Mount.—Fig. 8 illustrates a light polishing-wheel mount that may also be used for small emery or buffing wheels. A wheel *a* is shown on the left-hand spindle.

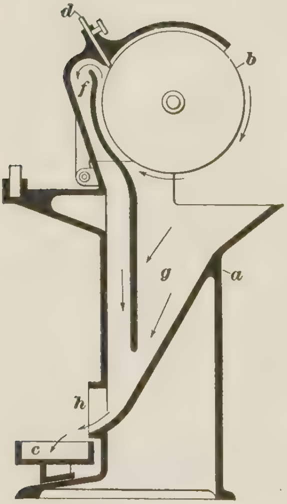


Fig. 9

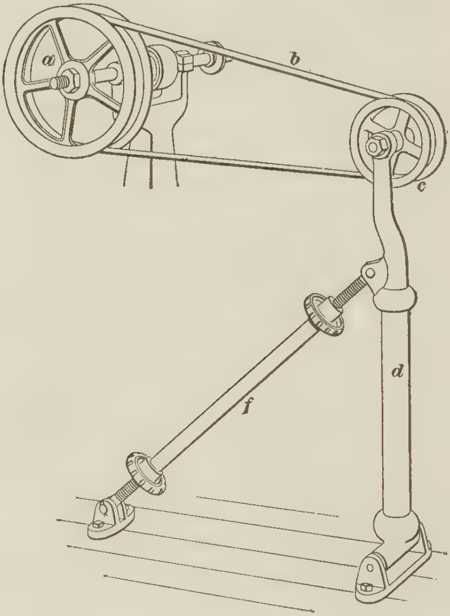


Fig. 10

The machine shown is mounted on a bench stand. Similar mounts are built that are erected on posts that stand on the floor. The machine is driven by a belt that runs on the pulley *b*, and has provision for a second wheel at *c*.

48. Enclosed Polishing Machine.—A form of enclosed polishing machine is shown in Fig. 9. The interior of the base *a* is so formed that the air current caused by the rotation of the wheel *b* will remove all dust caused in polishing and deposit it on the floor behind the machine or in the water tank *c*. The wheel rotates in the direction indicated by the arrow. At the back a shield *d* is so arranged that it can be adjusted to almost touch the face of the wheel. This shield stops the current of air rotating with the wheel and turns one current downwards through the passage *f*, while another current passes downwards through the passage *g*; but both air-currents are discharged at the back of the machine through the opening *h*. This machine was devised to polish small work.

49. Belt Polishing Machine.—Fig. 10 illustrates one form of mount for a polishing belt. A pulley *a* has been mounted on one end of an ordinary buffing-wheel or grinding-wheel arbor. The belt *b* passes over this pulley and the pulley *c*, which is supported upon a swinging arm *d*. By means of the brace *f* the tension on the belt *b* may be regulated. This belt is coated with glue and emery, or any suitable polishing material.

BUFFING

50. Buffing Wheels.—Sometimes buffing and polishing are considered one and the same thing; but a distinction should be made between them at the point where the finish becomes grainless. The buffed or grainless finish is obtained by means of soft wheels. *Felt wheels*, or those made of layers of felt covered with emery are sometimes used; but generally the *compressed wheels*, or those formed of layers of cotton cloth that are cut into round blanks about 12 inches in diameter with a hole in the center are used. These round blanks are piled one above the other until there are enough to form a wheel from 2 to 4 inches thick; they are then placed on the arbor of the machine, Fig. 8, and bound together at the center by collars and a nut. The larger these collars are, the harder will be the wheel when running; the smaller the collars, the softer will be the wheel when running.

When the wheel that consists of layers of cotton cloth is in place on the arbor of the machine, the edges of the cloth are presented to the work, or form the periphery of the wheel.

In use, this wheel is revolved (if 12 inches in diameter) from 4,000 to 6,000 revolutions per minute, according to the practice of the operator. The object of using cloth in this manner is to give a yielding wheel into the periphery of which the operator can press the work, which usually is irregular. In this way the cloth is made to rub every corner and curve of the work and the lines of its motion are in all directions, thereby not only polishing all corners and curves, but also giving a grainless surface.

51. For buffing purposes, *brush wheels*, or wheels surrounded by brushes of bristles or other materials, are frequently used. Brush wheels are more expensive than rag wheels and are not used extensively in machine shops.

Leather wheels are frequently used for buffing. For very small wheels, disks may be cut from ordinary thick leather; while when larger disks are required they are generally cut from walrus, or sea horse, hide, which can be obtained 1 inch or more in thickness and makes an excellent buffing wheel. These hides, though very expensive, are largely used where a very high grade of polish is required; for example, pistols, guns, and cutlery.

52. Cutting or Polishing Material Used in Buffing. In buffing, a cake made by compressing tallow, or other heavy grease, together with emery, crocus, flour emery, rouge, or other material is employed for cutting or polishing. The coarser material is used for roughing and the finer material for finishing, or "coloring," as it is known in the shop. This material is applied to the wheel by holding it firmly against the edges of the cloth, as the wheel revolves, until the edges become saturated; it is also applied from time to time as the operator wishes to change the cutting quality of the wheel.

53. Applications of Buffing.—Buffing is used for plated ware and for the peculiar surface that is common on bright vases, culinary articles, and lacquered surfaces. Much buffing is done by first cutting down with a rough material on the wheel, then finishing, or coloring preparatory to plating.

In some of the finer grades of work, this is accomplished by holding it against a very soft cotton-cloth wheel that has no cutting material upon it. If the pressure and speed are suited to the substance of which the article is made, a very bright surface will be produced.

With plated ware, the perfection of the surface after plating will never be greater than the surface on which the plating is deposited. After the article is plated, it is again taken to the soft buffing wheels and colored, which removes all stains from the plating bath and gives that peculiar luster that the operator calls "color."

Some work is first polished and then buffed, but in such cases the material is usually hard, such as steel, while brass and softer metals are not so treated.

HAND AND TOOL GRINDING

HAND GRINDING

54. The simplest grinding machines are those of the bench and floor types. These are used principally for offhand grinding, as general machine-shop work, and also for snagging castings, which means removing the rough places on castings by means of a grinding wheel. These machines should be of rigid design in order to absorb vibrations, and the bearings should be kept in good condition, as from the nature of the work, they are liable to get out of adjustment very quickly. The grains and grades found most satisfactory on bench and floor grinding machines vary so widely that it would be impractical to give them; but good all-round wheels are: grain 24, medium hard grade; and grain 36, between a medium and medium hard grade. These machines are usually driven by means of a belt from the main line countershaft, although a number of floor machines are now in use which have the motor attached and make a very convenient machine. Where such a motor is of variable speed, longer life can be obtained from the wheel by speeding up the motor as the wheel wears down. With constant speed motors, the surface speed of the wheel becomes slower as the diameter decreases, and the wheel therefore acts softer and wears away faster than if the surface speed was kept constant.

55. Simple Hand Grinding Machine.—The grinding machine used in foundries for smoothing castings, and which is illustrated in Fig. 11, is perhaps the most common type of a hand-grinding machine. These machines are made in a great variety of sizes, carrying wheels from 3 inches to 36 inches in diameter. The style shown is provided with rests *a* upon which the work may be placed while it is being ground. For truing grinding wheels, truing devices are permanently attached to the machine and shown below the rests, *b* being the axis on which the device works, *c* the truing wheel, and *d* the handle by means of which it is controlled. Whenever one of the wheels *e* gets out of true, the truing device can be brought into contact with the face of the wheel and moved across the face on the axis *b*, thus quickly truing

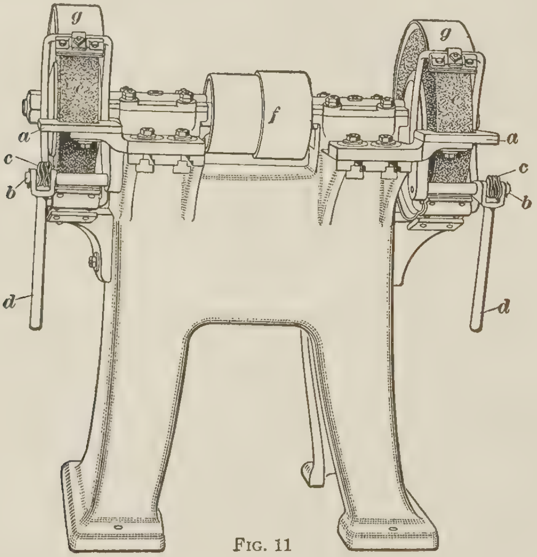


Fig. 11

the surface of the wheel. The wheels are driven by means of a belt on the pulley *f*. The grinding wheel guard or hood *g* is made of boiler plate.

In some cases, similar machines are used where considerable skill is required to produce the work; but as a rule this type is used only for comparatively rough work.

56. Swing-Frame Grinding Machines.—The particular field for swing-frame grinding machines is where the work is too heavy to be moved over the wheel and it is found more advantageous to move the wheel over the work. The older machines of this type are driven from a main line shaft by means of belts; but those of recent make have individual motors of variable speed, in order that the surface speed of the wheel may be kept constant and that less power may be consumed. If only one machine in a row is to be used and they are all driven from a main line shaft by means of a large motor, a considerable waste of power would result.

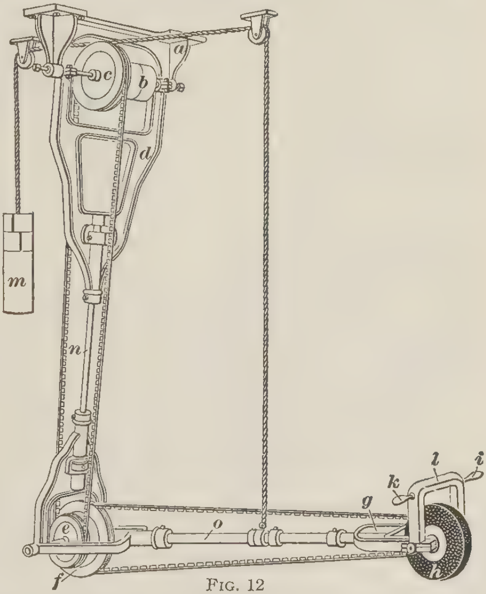


FIG. 12

The machine shown in Fig. 12 consists of a bracket *a* fastened to the ceiling that carries the countershaft on which are placed tight and loose pulleys *b* and the pulley *c*. This countershaft is driven by a belt that runs on the tight and loose pulleys *b*, while the emery wheel is driven by a belt on the pulley *c*, which drives the pulley *e*, which is permanently attached to the pulley *f*.

57. The belt on the pulley *f* drives a pulley on the grinding-wheel shaft, thus imparting power to the grinding wheel *h*. The swinging frame *d* is supported from the countershaft bearings and the swinging frame *g* is counterbalanced by means of a weight *m* and a suitable rope passing over the pulleys, as shown. The wheel *h* is mounted on a shaft at the end of the swinging frame *g* and is provided with a yoke *l* and handles *i* and *k*, by means of which its motion can be controlled. The connecting portion *n* below the swinging frame *d* is so arranged that it can swivel in the frame *d*, and the portion connecting the swinging frame *g* with the shaft carrying the pulleys *e* and *f* is also arranged so that it can swivel. The result is that the grinding wheel *h* can be turned to any angle or into almost any plane, either horizontal or vertical. The operator is thus enabled to grind both surfaces and edges of the work, or to round corners. This class of machine has found a great field of usefulness, especially in the finishing departments of shops producing rather large work; but considerable skill on the part of the operator is required to produce a smooth surface with it.

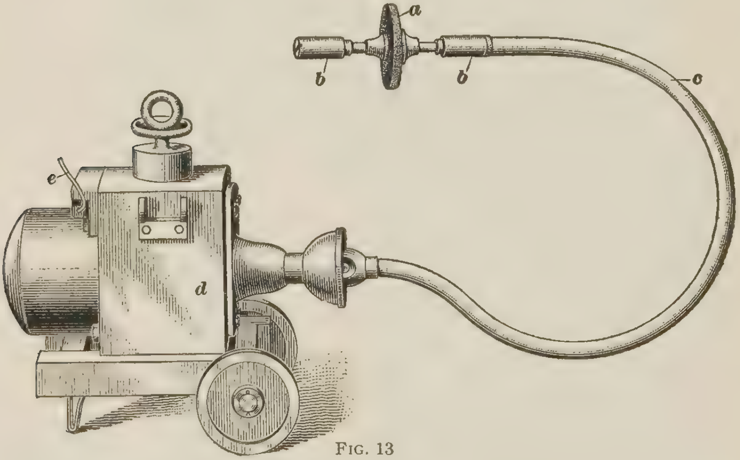


FIG. 13

58. Flexible Shafts.—Flexible shafts are a modification of the swing-frame machine and usually carry wheels not over 8 inches in diameter. They are generally operated by means of an individual motor which is conveniently moved around the shop on a truck. In Fig. 13, *a* is the grinding wheel which is operated by means of the handles *b*. The flexible shaft is enclosed in the tube *c* and is driven by the motor *d*. The electric wires *e* are usually of sufficient length to reach from the wall to the center of a good-sized room.

59. Disk Grinders.—Disk grinders, Fig. 14, are used to produce smooth surfaces on flat pieces of work. However, if the piece to be ground is very rough and irregular and there is much material to be removed, it is not practical to do it by means of disk grinders, as the disks become cut and scored, and the operation is a long one. The abrasive is usually bonded together by means of glue on either paper or cloth, and this in turn is cemented to an iron disk *a* which is mounted on the machine. It is sometimes found advantageous to mix two different abrasives together, for instance, alundum and crystolon. This can be done when the abrasive is glued on a disk, although it has not been found practical in the case of grinding wheels, owing to the differences in expansion on heating and contraction on cooling of the different abrasives. At the left-hand side there is a simple flat table *b*, Fig. 14, whose upper surface is scraped at exactly right angles to the disk; by holding any flat surface on this table, a surface at exactly right angles to it can be ground by the disk.

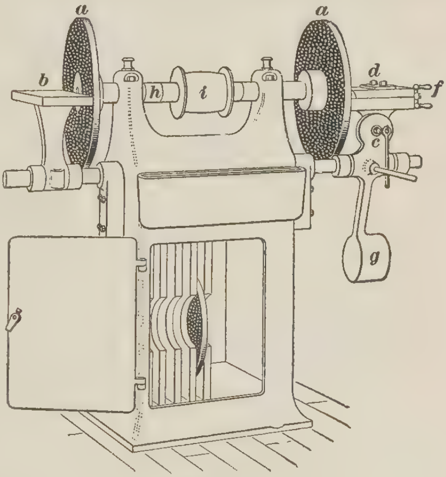


Fig. 14

60. The manufacturers claim that it is easily possible to grind small work within the limit of .001 inch on these machines. When it is desired to grind at any other angle than a right angle, an attachment similar to that shown at the right-hand side of Fig. 14 may be used. This is provided with a graduated circle on the piece *c* by means of which the table can be set at any angle to the disk. It is also provided with a sliding guide *d* controlled by the handle *f* which operates the feed-screw. By arranging a stop or indicator disk on the handle *f*, the exact thickness to which the work is ground can be gauged within .001 inch; and by means of the graduated circle on the piece *c*, the angle between the faces can be accurately determined. This head is also provided with a balance weight *g* by means of which it can be arranged to oscillate within limits, thus swinging the work back and forth across the face of the grinding disk and so reducing the liability of producing scratches upon the surface. The disks are carried on the shaft *h* driven by the pulley *i*. The machine is mounted on a substantial base, which is provided with a cupboard for the grinding disks.

The disk grinding machine does not replace any particular machine tool in the shop as much as it serves to do work that is usually done by filing; but a large amount of work that is ordinarily done at the bench may be done on a machine of this class.

61. Advantages of Disk Grinders.—Among the advantages claimed for disk-wheel grinding may be mentioned the time saved in chucking the work as it is allowed to float when pressed against the grinding disk and therefore need not be held rigidly. The disks cover a wide area so that grinding can be done over a large portion of the piece at one time. The iron disks used are practically unbreakable so that there is no danger of accident to the operator, as there is when grinding wheels are used; they can be operated at a very much higher speed, and they will cut faster on certain classes of work. The difficulty of being out of balance is avoided, a true surface is left on the work, and all grinding is done dry. The disks vary from 12 inches to 53 inches in diameter, according to the size of the piece to be ground.

Their thickness is determined by their size; the disks are made thick enough to withstand the stresses met in practice.

62. Double Disk Grinders.—The manufacturers of disk grinders have recently put on the market a very convenient form of machine, which has two disks facing each other, one of which is movable so that the space between them can be adjusted for any size of work. Both sides of a flat piece can be surfaced at one time, which is a great advantage for many operations.

63. Ring Wheels.—In certain classes of work, such as smoothing up very rough, uneven surfaces, much trouble is experienced in attempting to use the ordinary disk. For work of this kind, an improvement on the disk grinder has been devised in which ring wheels, or cylinder wheels, as they are sometimes called, operate. These wheels, shown in Fig. 15, work on the same principle as the disk, except that the grinding surface is usually not more than 1½ inches to 2½ inches. In the illustration *a* is the grinding wheel, *b* the chuck body, *c* the split-clamp ring, *d* the nut to move out the grinding wheel as it wears, and *e* the hub. This type of wheel adapts itself very well to grinding a smooth surface on a rough and irregular object, and has the advantage over a cup wheel, in that it is

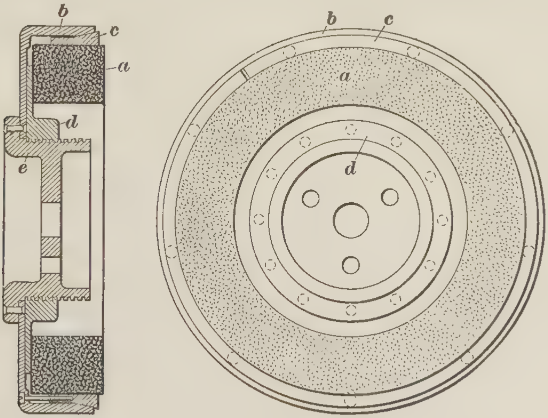


FIG. 15

held in a substantial chuck and there is less danger from breakage.

The use of cylinder or ring wheels has the added advantage over disk grinders, in that the whole grinding surface is running at practically the same speed. With disk grinders this is not the case, since the portion near the center of the disk travels very much slower than the portion near the periphery, which sometimes leads to trouble, in that the cutting particles near the periphery, which are traveling faster, do more work and also dull more rapidly than those near the center; it will be found that the disk has lost its cutting efficiency near the circumference while the center is still sharp.

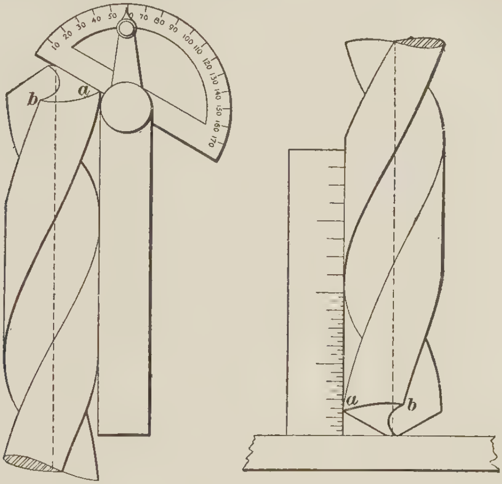
TOOL GRINDING

DRILL GRINDING

64. Form of Drill Point.—The form of drill point that will give the best results will vary for different classes of work, and before grinding the correct form for the work to be done should be known. It is very important that this form shall be maintained whenever the drill is ground. The drill point should always be perfectly symmetrical, and when cutting, should produce similar cuttings on each side.

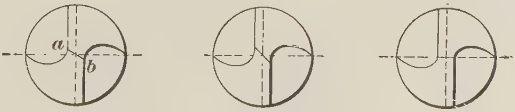
65. Hand Grinding.—To grind a drill by hand so that the above conditions may be fulfilled requires the greatest skill and care. Hand grinding is usually done by holding the tool on the grinder without a gauge, and depending only on the eye for the correct cutting and clearance angles. Sometimes a flat drill is tested by pressing the one cutting edge against a smooth piece of wood, while holding the drill in a certain position, then turning it and pressing the other edge on the same mark, still maintaining the same position of the shank. If the two marks coincide, the drill is supposed to be well ground. The accuracy of this test depends entirely on the skill of the workman, but remarkably good results are often obtained.

66. Measuring the Cutting and Clearance Angles of Twist Drills.—In the case of a twist drill, a better test is made by a gauge, or a protractor, set at the required angle, as shown in Fig. 16 (*a*). By turning the drill so as to bring the protractor from *a* to *b*, the clearance angle may be observed, and in this way the two sides may be compared.



(*a*) FIG. 16 (*b*)

Another method often used is illustrated in Fig. 16 (*b*). The point of the drill is set on a plane surface or on a straightedge, and a scale held against its side, as shown. The heights of the corners *a* from the point are thus measured. If the two sides are alike, the drill is turned, and the heights of the corners *b* are measured, thereby determining whether the clearance angles are equal. The scale is then laid along the cutting edges, and if all three corresponding measurements agree on both sides, the point is symmetrical.



(*a*) (*b*) (*c*)

FIG. 17

67. Angle and Length of Scraping Edge.—The planes of the clearance faces intersect in the line *a b*, Fig. 16 (*a*). The angle of this line with a center line parallel to the cutting edges is determined by the clearance angle. The angle shown is about correct. When the angle is too small, as in Fig. 17 (*b*), or too great, as in Fig. 17 (*c*), the drill will not work well. In order to give strength to the drill, the center is made thicker as it approaches the shank, and it is obvious that as the cutting edges are ground back, the length of the line *a b*, Fig. 17 (*a*), increases. When this increase becomes objectionable, the flutes should be ground out until the point is reduced to its original thickness. In this operation, care must be taken not to change the shape of the flute.

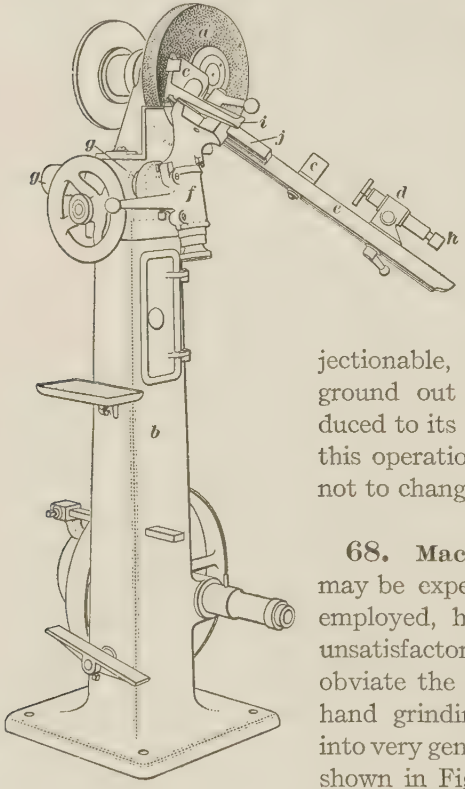


Fig. 18

68. Machine Grinding.—As may be expected from the methods employed, hand grinding is often unsatisfactory, and machines that obviate the difficulties met with in hand grinding have been brought into very general use. The machine shown in Fig. 18 may be taken as a fair representative of twist-drill grinding machines. The grinding wheel *a*, which is rotated by means of a belt, is supported on a column *b* at a convenient height from the floor. The drill is held on two **V**-shaped supports *c* and an end rest *d*, all of which are held on an arm *e*, which is supported in a bearing *f*, about whose axis the arm *e* is free to swing. The bearing *f* is supported on the end of the arm *g* and may be moved nearer or farther away from the wheel *a* by sliding the arm endwise in its bearing. It may be clamped at any position.

69. To grind the drill, it is laid on the **V**'s *c*, Fig. 18, and the end rest *d* is adjusted to hold the drill near the wheel. The lip of the drill is laid against a gauge that is hidden behind the upper **V**, and the arm *e* is rotated about the axis *f*. The drill is fed slowly toward the wheel by turning the screw *h* until the drill is ground to the desired edge. The opposite cutting edge is then ground without changing the setting of the machine.

70. Form of Clearance Face.—From this construction it is evident that the metal back of the cutting edge will be ground away in the form of an arc of a circle. This has been thought objectionable, but the use of these machines has demonstrated that if the radius is properly adjusted for each size of drill, the arc immediately back of the cutting edge will be so flat, and will approximate so closely to a plane, that the supporting edge is practically not weakened. As the arc runs farther away from the cutting edge, it, of course, deviates more from the true clearance angle; but before any deviation is noticeable, the arc has run so far back that the support of the cutting edges is not affected.

71. Length of Radius.—The length of the radius is adjusted by moving the arm *g* in or out of the bearing, the position being determined by an ingenious device shown at *i*, Fig. 18. In order to make the adjustment for the drill, the arm *g* is loosened and drawn out a short distance. The upper **V**, *c*, is then loosened and moved up until the opening between the projection *i* and the projection *j* on the arm *e* just permits the drill to pass through. The **V** is clamped in that position, and the arm *g* is again moved in until the lip gauge, already mentioned, just clears the wheel. The end rest *d* is then set to the proper position, and the drill laid on the **V**'s and ground, as already explained. These adjustments can be made with very little loss of time, and a perfectly symmetrical drill point is assured. A machine of this type will grind drills ranging from $\frac{1}{8}$ inch to $2\frac{1}{2}$ inches in diameter.

GRINDING OF LATHE, PLANER, SHAPER, AND BORING-MILL TOOLS

72. Hand Grinding.—When the lathe, planer, shaper, and boring-mill tools are ground by hand, a machine similar to the one shown in Fig. 19 is used, and the angles and shapes are obtained by simply holding the tool to be ground against a revolving grinding wheel. This operation requires great skill on the part of the operator and it is practically impossible for even a good operator to grind two tools to exactly the same dimensions. However, in small shops, where there are few of these tools to be ground, this type of grinder is often used.

73. Method of Supplying Water.—The machine shown in Fig. 19 is arranged to provide for a supply of water without the use of pumps or pipes, and also has a truing device arranged in the wheel guard. The water tank *d*, which is shown in section, is filled with water, the water trough *a* being raised to its highest level by means of the screw *b* and the lever *c*, the trough being pivoted at one end. The water trough surrounds the lower part of the wheel and when in its highest position prevents water from wetting the wheel; as the trough *a* or its forward end is lowered, it sinks in the surrounding water and allows it to flow in around the wheel. The trough is lowered sufficiently to obtain the amount of water desired by the operator; the wheel throws the water out at the rear, but an equal amount runs in at the forward end, thus keeping the supply constant.

74. Truing Device.—The truing device consists simply of a threaded roll *h*, Fig. 19, mounted on the end of a rocking lever, so that the operator can force it against the revolving wheel by means of the screw *f*. This truing device is always ready for use.

75. Tool Rest.—The tool rest *i*, Fig. 19, is surrounded by a guard *e* so arranged with a balance weight that it normally occupies the position shown. When the operator wishes to grind a tool, he places it on the point *g* and presses it downwards until the tool comes in contact with the rest *i*. When the tool is removed, the guard rises and prevents water from splashing out in front, no matter how large an amount of water may be supplied to the wheel.

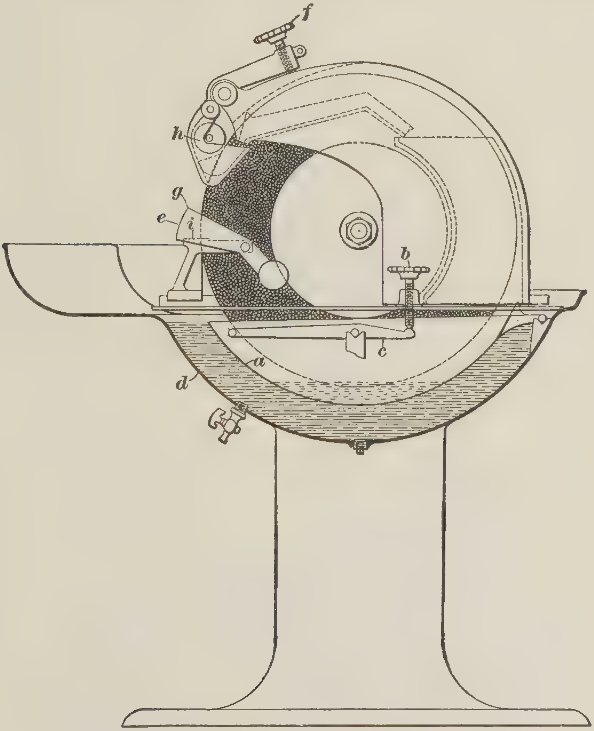


FIG. 19

76. Machines for Duplicating Shapes.—With the growth of machine manufacturing, replacing as it does the older method of machine making, it has become the practice in large machinery establishments to make the lathe and planer cutting tools in large lots. These tools are all ground to the correct shapes and are ready for use. The old ones are reground and sharpened to the standard forms and then placed in the tool room, convenient to the workmen.

The shapes of the tools vary in different establishments; but usually each establishment establishes standard shapes for its cutting tools and the operator follows the blueprint of standards that is generally placed on holders attached to the machine. Tool grinders must be free from vibration, and adjustable for grinding proper angles on all sizes of tools.

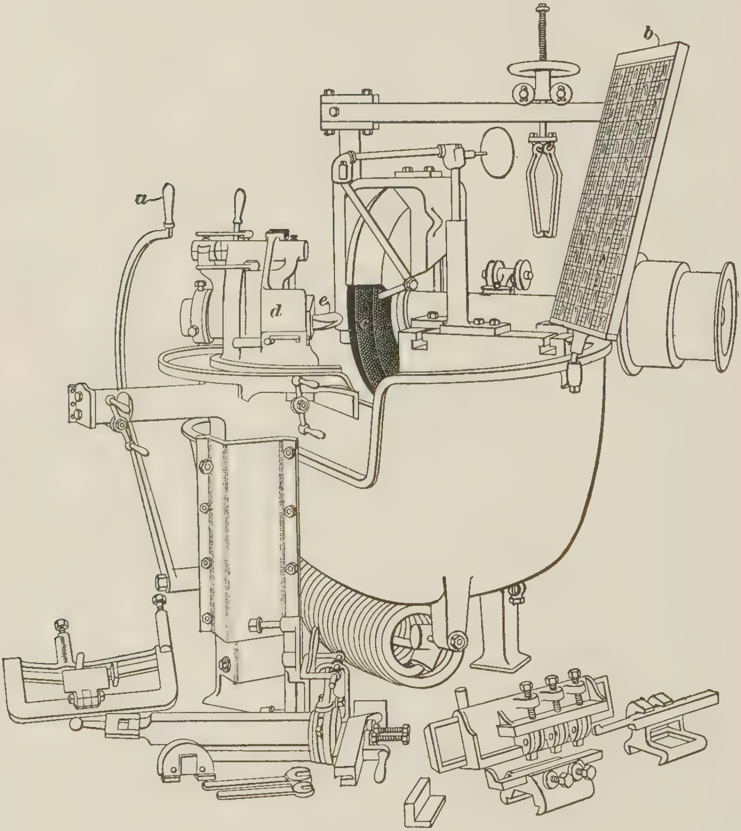


FIG. 20

Another advantage in the use of duplicate shaping machines is the saving of time, for where hand grinders are employed, several men frequently endeavor to use the same machine at once. Another important item is the employment of unskilled labor. However, it is sometimes found advantageous to rough grind tools on a hand machine and finish them by means of the duplicate shaping machine.

77. Sellers Grinding Machine.—The Sellers machine shown in Fig. 20 is called a *universal tool-grinding and shaping machine*. It is so constructed that, with its fixtures and attachments, the accuracy of the form to be ground is not dependent on the skill of the operator, but is obtained by placing the various holders and attachments at the angles required, these being graduated and marked so that if the operator places them at the right graduation and angles, the accuracy of the grinding will be insured. When the tools are placed in the various holders, the operator moves them against the wheel by the use of a lever shown at *a*. Water is supplied to the grinding wheel by means of a rotary pump, and on one side of the machine is attached a diagram of instructions *b* for obtaining the standard shapes.

78. The Sellers machine is designed to present a line contact between the grinding wheel and the work being ground. The makers believe that it is absolutely necessary, in order to efficiently grind steel tools by means of rapidly cutting wheels, that the contact between the two should be a line and not a surface; hence, if it is desired to grind a plain face of a tool, the wheel must have a cylindrical or conical surface past which the surface to be ground must be moved in a plane. They further state that the plane face of the wheel cannot be used for this purpose because it and the surface being ground will soon coincide, with the result that very little cutting will be done, though considerable heat will be produced.

79. The machine shown in Fig. 20 is provided with a wheel with two conical faces *c* and the tools are held in a suitable fixture *d*, one tool being shown at *e*. The machine will not only grind all angles and circles with clearance, but it will also, by the use of forms, grind irregularly shaped cutting tools. On this account, it probably has as great a range as any machine on the market and is remarkably well adapted for shops having a large variety of tools.

80. When to Grind Tools.—It is good practice in making tools to grind before hardening, if possible, because the tool is then in a soft condition, and the material can be removed much more rapidly than after it is hardened. In order to remove the outer scale, $\frac{1}{16}$ inch is ground off the tool at the first grinding after is has been hardened; otherwise, the tool will become rough soon after starting to cut, and have a short life. A large continuous stream of water must be used when wet-grinding tools. The tools should be ground when just a little dull; otherwise, they dull very rapidly and more grinding is necessary than if they were ground as soon as they became dull. Chattering of the work is one result of dull tools.

81. Grade of Wheel.—In selecting wheels for tool grinding it should be understood that the result to be obtained is dependent on many conditions in the wheel aside from the size of grain. The grade of the wheel plays a very important part in the manner in which it does its work. The grinding wheel for tool grinding should be soft enough to cut freely without requiring too great pressure and without glazing. If only very large tools that present broad surfaces to the wheel are to be ground, the wheel should be softer than if only those tools presenting very small surfaces are to be passed over it. The exact number of abrasive and the grade of wheel to be used in all cases cannot be given, because conditions vary so much. Wheels for this purpose should be so made that the desired surface on the tool will be dependent on the grade of the wheel rather than the grain; that is, the wheels should be quite coarse and very porous, for a coarse wheel will produce quite a fine finish if of the right grade, trued properly, and run at the right speed for the work in hand.

82. Some workmen prefer to use a coarse wheel for shaping the tool, and a much finer one, quite soft, for a slight cut to give the desired surface for a cutting edge. In most cases, however, only one wheel is necessary, provided an oilstone is used for the finishing touch. The users of tool grinders frequently select wheels much too hard. It is a common complaint among manufacturers of tool grinders that they are obliged to send out wheels that are much harder than the purpose requires. This is due to the fact that workmen generally do not understand how light a touch is required to grind work very rapidly on a good wheel. A soft wheel, suitable for grinding tools rapidly, will remove a large amount of material with a very light touch of the tool upon it.

83. Grinding High-Speed Steel Tools.—The question is often raised, should water be used when grinding high-speed steel tools? There are three possible methods of procedure: the tools may be ground dry at the ordinary temperature; they may be ground wet, that is, on an ordinary wet tool grinder; or, they may be preheated to about a working temperature and ground dry.

Checking is a difficulty often encountered when grinding tools of high-speed steel. A tool which is checked has fine cracks all over its surface. During the grinding operation, the part of the tool in contact with the grinding wheel is heated to a high temperature, as shown by the sparks thrown from the wheel. Should water come in contact with the portion of the heated tool, checking will result. However, if water can be so directed on the tool that there is a continual flow directly on the point in contact with the wheel, the temperature of this point will be kept relatively low and checking will be avoided. This is a very difficult thing to do. If the tools are brought to the grinding machine, heated to a temperature at which they will be used under normal working conditions, checking will very rarely result. Naturally, no water is used with this method of grinding.

84. The water in wet tool grinding is seldom kept clean and consequently the wheel will become gummed, or "slicked." The cutting ability of the wheel will be reduced and the operator will use too great pressure when grinding. The smooth condition of the wheel face and the extra pressure give rise to great friction between the tool and the grinding wheel and the tool is heated so rapidly on the outer surface, or skin, that checking almost always results. Some operators use a wheel very much harder and finer than is necessary, the thought in mind being to employ a wheel which will last a long time. The cost of ruined tools usually far exceeds the extra cost of a softer and coarser grinding wheel of the proper grade and grain, which would sharpen the tool satisfactorily at a very light pressure.

GRINDING CUTTERS, REAMERS, AND TAPS

85. Universal Tool and Cutter Grinder.—Like other modern grinding machines, the universal tool and cutter grinder used today is heavier and its adaptability and range is wider than the machines of a few years ago, making it possible to do all classes of grinding incidental to a tool room. As the name implies, these machines will grind any style or shape of milling cutter, reamer, tap, counterbore, etc. They are also very efficient for cylindrical, internal, surface, and angular grinding.

86. When to Grind.—When making milling cutters and reamers, they should be so ground as to give them true cutting edges. They should also be ground when they become dull to maintain them in the best serviceable condition. The condition of all cutting tools should be watched carefully, because when a tool or cutter begins to get dull, if it is not immediately sharpened it soon becomes worse, and requires more power to drive it. Furthermore, the increased friction produces sufficient heat to affect the temper of the tool seriously.

Most tools when but slightly dulled may be ground many times without injury either to their form or temper. The formed cutters, of which the gear-cutter is perhaps the most common type, may be ground on the faces of the teeth, as long as the teeth last, without changing their form. If kept in good condition, a very slight grinding is sufficient to sharpen the cutter; but, if the cutter is kept at work when dull, the formed surfaces become worn back from the cutting edge, thus necessitating the removal of $\frac{1}{32}$ inch or more from the faces of the teeth in order to sharpen them.

87. Cutter and Reamer Grinder.—The machine shown in Fig. 21 is a grinder arranged for the sharpening of milling cutters and reamers. This machine consists of a base *a* that carries the wheel stand *b*. A graduated saddle *c* is placed on top of the base; this saddle carries the slide *d* in which the table *e* works. The table can be moved toward or away from the grinding wheel by means of a feed-screw that is operated by the hand wheel *f*. The table can be swiveled horizontally, the saddle *c* having graduations that show the angle between its line of motion and the axis of rotation of the spindle. A feed-screw that works in a split nut and is

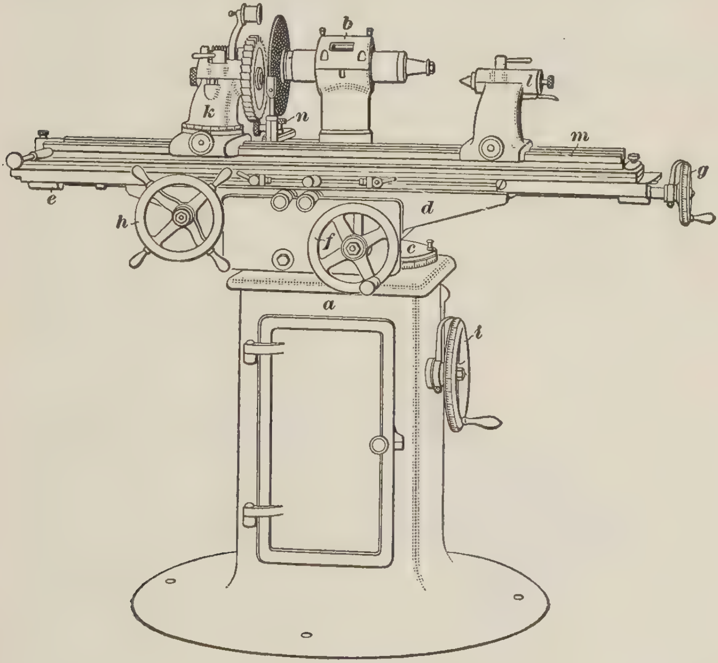


Fig. 21

operated by the hand wheel *g* is used for traversing the table; when the split nut is unlocked from the feed-screw, the table can be traversed rapidly by means of the pilot wheel *h*. The height of the grinding wheel above the table can be adjusted by means of the hand wheel *i*. A headstock *k* and a footstock *l* are provided for grinding work between centers. The headstock and footstock are attached to an auxiliary swivel table *m*, which is placed on top of the regular table *e*; the machine is thus adapted for taper work to be done between centers. An adjustable standard *n* for a guide finger is provided; this finger prevents rotation of the cutter or reamer that is being ground.

88. If a driving pulley is fitted to the headstock, the machine may be used for grinding small cylindrical and taper work between centers, and by the aid of proper attachments chuck work and internal grinding of a light kind may be done. The wheel stand may be swiveled to bring the wheel over the table, and the machine may be used for light surface grinding.

89. Cutter and reamer grinding machines are made in different ways by the various manufacturers; but most of the machines embody the same features and differ only in the design of the details. The following illustrations and examples of cutter and reamer grinding refer to no particular make of machine but have been selected entirely for the sake of the principle involved in each operation. This fact is mentioned here in order that the reader may not think that the illustrations and explanations given refer to the machine shown in Fig. 21.

Although the swiveling parts have a scale attached to them by means of which it is possible to swivel to any desired angle, good practice demands that a trial piece be ground before grinding the regular piece, in order to assure the fine degree of bevel required by most grinding operations.

90. Truing the Wheel.—To obtain satisfactory work with universal tool and cutter grinders, the grinding wheel should always be trued with a diamond tool, a good form of which is shown in Fig. 22. A small diamond *a* is set centrally in the end of a cylindrical rod or shank *b*, to the other end of which is fitted a suitable wooden handle. The diamond tool should be held in a rigid tool post, which is firmly clamped to the table of the grinding machine and the wheel is trued by passing the table back and forth in front of the wheel. If the diamond is passed back and forth until it has completely stopped acting on the wheel, the wheel will act very much harder than if it is trued by a few rapid passes of medium depth. For this reason, one operator often obtains satisfactory results where another operator will complain that the wheels are too hard and that he cannot use them because they burn and glaze the work.

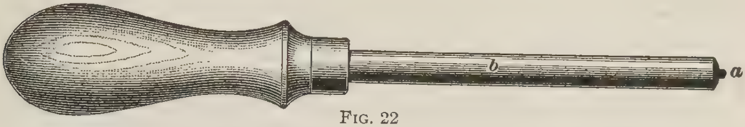


FIG. 22

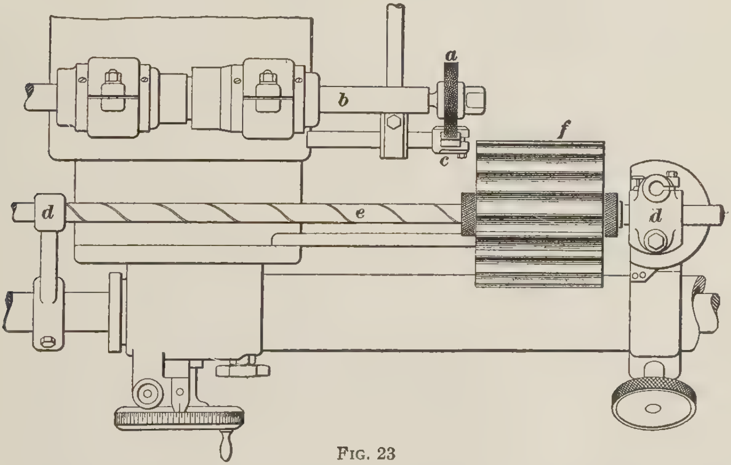


FIG. 23

91. Grinding Cylindrical Cutters.—Fig. 23 illustrates the grinding of a cylindrical milling cutter in a machine somewhat different from that shown in Fig. 21. In the illustration, which is a top view, the grinding wheel *a* is shown mounted on the spindle *b*; beneath the grinding wheel is a guide finger *c*. Clamps *d* hold a cutter rod or bar *e* on which the cutter *f* is mounted. A helical groove is sometimes cut in the cutter bar *e*, so that any particles of abrasive that may collect on the bar will be brushed into the groove by the backward and forward movement of the cutter. Since the sizes of the holes in milling cutters vary with their diameter, some provision must be made for grinding all sizes of cutters within the capacity of the machine. This is done either by making a suitable bar for each size of hole or by making bushings for the larger sizes of holes, so that cutters having large holes may be ground on the small bar. Some cutters and shell reamers have taper holes; these must be provided with a bushing having a straight hole fitting the bar, the outside being fitted to the taper hole in the cutter or reamer. When this bushing is in place in the cutter, the latter may be ground the same as any cutter having a straight hole.

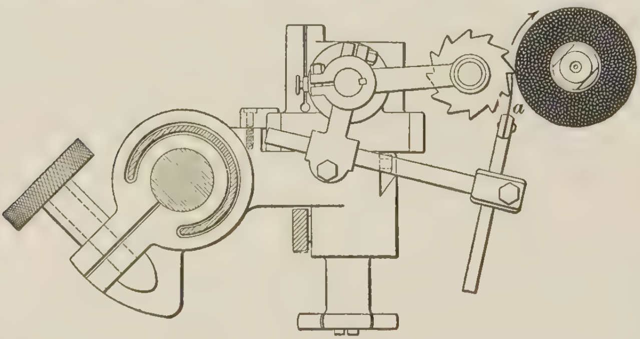


FIG. 24

92. Form and Position of Guide Finger.—The cutter having been mounted on a suitable bar, the guide finger *a* is adjusted under one of the teeth, as shown in Fig. 24, so that the grinding wheel is in contact with the back of the land of the tooth. This guide finger should be somewhat wider than the face of the grinding wheel, as shown in Fig. 23, in order that the cutter may rest on the finger before it reaches and after it leaves the grinding wheel. If the finger is narrower than the face of the wheel, the latter is liable to catch and score the cutter while the latter is engaging or leaving the wheel. The guide finger should always have its top filed so that it is in contact throughout its width with the face of the tooth.

93. Precautions for Cutter and Reamer Grinding. Cylindrical cutters, whether their teeth are straight or helical, are ground by moving them past the face of the grinding wheel. The modern way is to have the wheel revolve toward the cutting edge of the tooth as shown in Fig. 24; that is, to have it revolve in such a direction that it tends to press the tooth that is being ground away from the guide finger. It is, however, the practice of some concerns to have the wheel revolve in the opposite direction. The teeth are then ground one by one, preferably by light cuts, going several times around the cutter to sharpen it. In order that the cutter may last well, it is essential that the temper should not be drawn from the teeth, or as the shop man expresses it, "the cutting edges must not be burned." Since cutter-grinding machines are not arranged to permit the flooding of the work with water, overheating can only be prevented by taking light cuts.

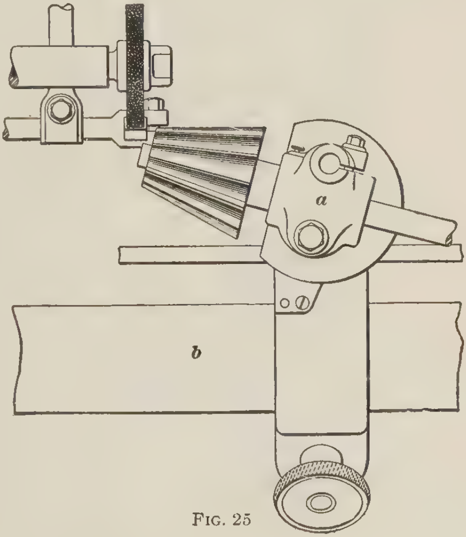


Fig. 25

Cutters ground by sliding them along a cylindrical bar become cylindrical themselves, because the distance between the axes of rotation of the grinding wheel and the cutter remains constant at the point of grinding, irrespective of whether the two axes are parallel or inclined to each other.

The grinding wheel retaining its size, it follows that all points of all teeth of the cutter will be at the same distance from its axis; that is, they will be on the surface of a cylinder.

94. Grinding Shank and Angular Cutters.—Some cutters, especially those having shanks, cannot be ground on a bar in the manner just described; such cutters are mounted in a suitable socket and ground cylindrical, or to a given angle, by adjusting, by trial, the device in which they are mounted. Angular cutters cannot be ground by sliding them along a bar, and the same device used for shank cutters may be used for them. Thus, the cutter may be mounted on a bar held in a swivel head *a*, Fig. 25, which is set, by trial or by graduations, to the required angle. The guide finger having been adjusted, the cutter is traversed past the face of the grinding wheel by moving the table *b* to which the holding device is attached.

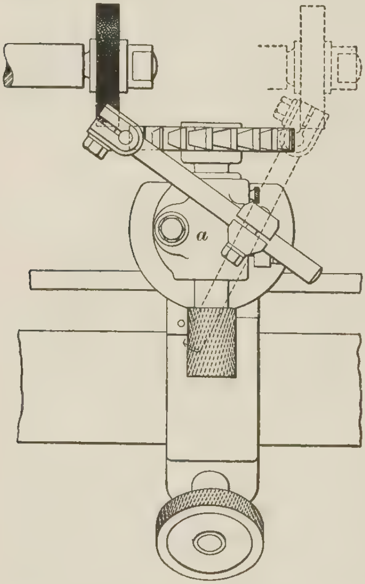


Fig. 26

95. Grinding Teeth of Side Milling Cutters.—For grinding the teeth on the side of side milling cutters, the cutter must be attached to the headstock by means of a suitable socket or arbor, as shown in Fig. 26, where *a* is a holding device or headstock. For want of room, the guide finger can seldom be applied to the side tooth that is being ground; in most cases the finger must be applied to the periphery of the cutter. The guide finger should be so placed that the pressure of the cut will be away from it; hence, the finger must be placed in an opposite position whenever the cutter is reversed after grinding one side. In Fig. 26 this fact is indicated by showing the new position of the finger and the grinding wheel in dotted lines. If the cutting edges of the side teeth are to lie in a plane, the holding device *a* must be swiveled to secure this condition.

96. Use of Cup Wheel.—For some kinds of tool grinding and cutter grinding, a cup wheel may be used to advantage. An example showing how the cup wheel is applied is given in Fig. 27, where an inserted-blade side milling cutter *a* is seen mounted on an arbor held in an adjustable holder *b*. If the guide finger *c* is used on the side of the cutter, as shown, the cutter must be clamped while grinding each tooth as the work passes off from the guide finger or tooth rest before cutting begins. The tooth rest acts as a spring pawl when revolving the cutter. The holder is made adjustable in a vertical direction, in order that the axis of the cutter may be inclined, in respect to the axis of rotation of the grinding wheel *d*, until the desired degree of clearance is obtained.

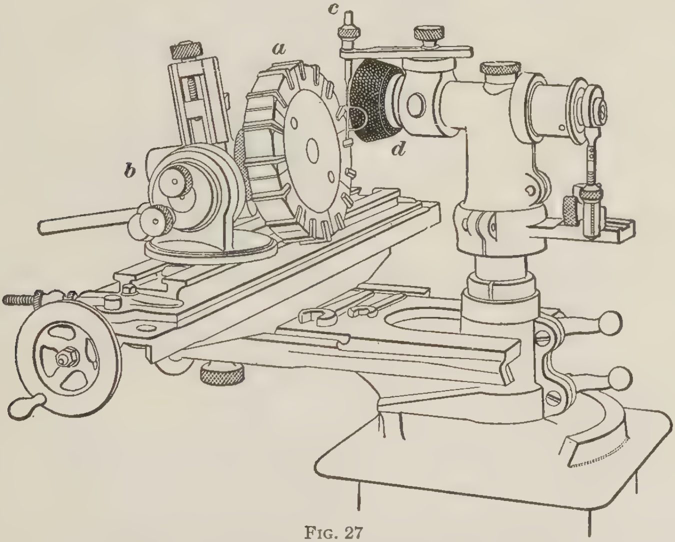


FIG. 27

The loop at the back of the tooth rest is for the insertion of the thumb of the operator when it is desired to spring the rest back to clear the teeth. The benefit to be derived from the use of a cup wheel is the well-supported cutting edge that is given to the cutter. The teeth on the side of the cutter can be ground so that their cutting edges lie in a plane, or they can be so ground, by a proper horizontal adjustment of the holder, that their inside corners will have a slight relief. If the holder can be swiveled sufficiently, angular cutters may be ground with a cup wheel. The depth of cut is regulated by feeding the cutter toward the wheel, and the grinding is done by traversing the cutter past the wheel.

97. Grinding a Side Milling Cutter.—Fig. 28 shows how a side milling cutter may have the teeth on its periphery sharpened in the universal grinding machine. A guide finger *a* is fastened to a suitable bar *b*. This finger should always be at rest with respect to the grinding wheel; that is, its position with respect to the grinding wheel should not change. When the guide finger is attached to the wheel base, it occupies a fixed position in front of the wheel, and every part of the tooth that is being ground must travel over it and pass the wheel in exactly the same relative position. This insures that the backing off is at a constant angle throughout the length of each tooth and is the same for all teeth.

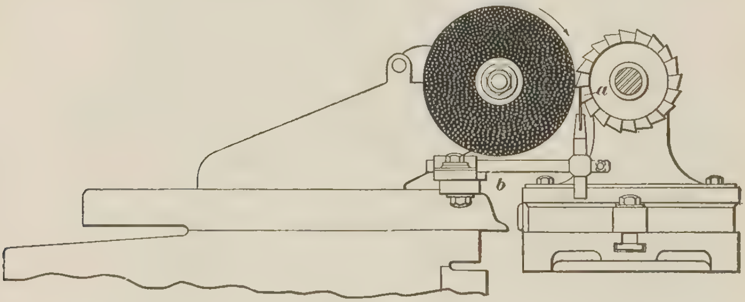


FIG. 28

98. Sharpening Formed Cutters.—Fig. 29 shows the method of grinding a formed gear-cutter. The cutter is mounted on a stud *a* in such a manner that the axis of rotation of the grinding wheel *b* is in the plane midway between the sides of the cutter. A guide finger *c* is set against the back of the teeth and is so adjusted as to make the face of the teeth radial. The slide on which the stud is carried may be pushed in or out by hand while the table remains stationary.

When formed cutters are ground by hand, a rest is placed in front of the wheel and the cutter laid upon this rest. The cutter is then pushed and pulled back and forth while the face of the tooth is held against the grinding wheel. The rest is often dispensed with in grinding formed cutters; considerable care will then be required to grind the faces of the teeth at right angles to the sides of the cutter. The wheel used should be of the dished type, as shown in Fig. 29.

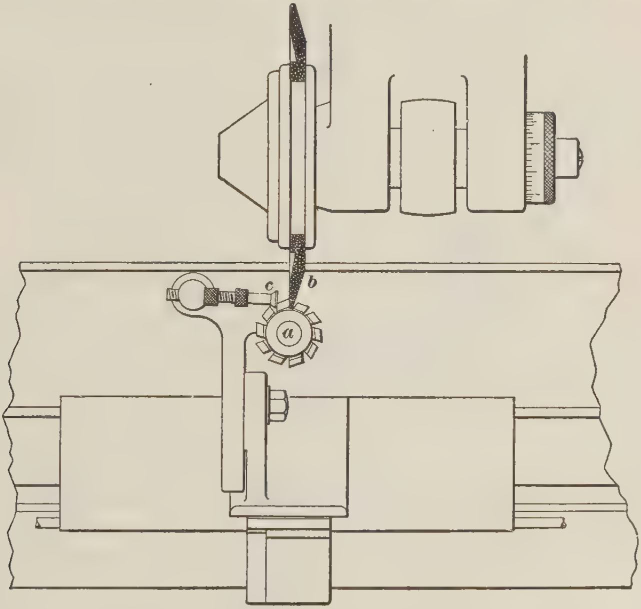


Fig. 29

99. Grinding Spiral Mill.—To grind a spiral mill, the tooth rest *a* shown in Fig. 30 is adjusted to the grinding wheel head, a straight wheel *b* is used, and the cutter *c* is held firmly against the tooth by hand. The proper clearance is obtained by setting the grinding wheel the required distance above the axis of the mill.

100. Grinding Cutters in Place.—Large milling cutters are often ground while on their own arbors and in the milling machine, using a special grinding device for the purpose. This is done for two reasons: in the first place, their size prevents them from being ground in a cutter grinder; in the second place, grinding them on their own arbor insures that they will run true.

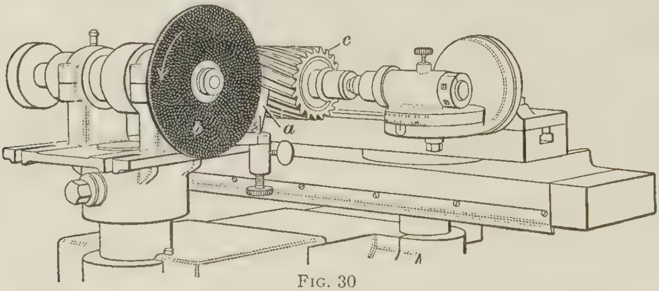


FIG. 30

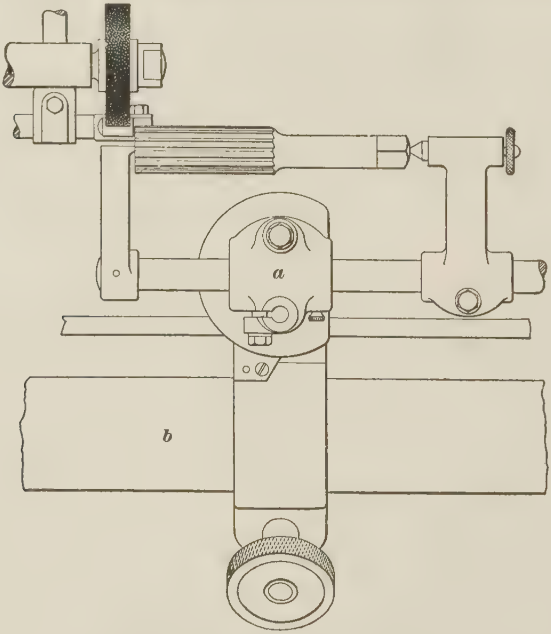


FIG. 31

101. Reamer Grinding.—Cylindrical and taper shell reamers may be ground in the same manner as milling cutters, sliding them along a bar if the reamer is cylindrical, and using a holding device if the reamer is tapering. In most cases it will be necessary to make a bushing for cylindrical shell reamers, since they usually have a tapering hole.

Reamers that may be classified under the general heading of solid reamers generally have a center at each end. Such reamers are ground between centers, as shown in Fig. 31. For grinding cylindrical reamers, the centers are adjusted so that the line joining them, which is also the axis of the reamer, is parallel to the line of motion of the table; for taper reamers, the axis of the reamer is set at the required angle to the line of motion. In this particular case, the centers are not clamped directly to the table, as in the cutter grinder that was illustrated in Fig. 21, but to a holding device *a*, which in turn is clamped to the table *b*. The grinding is done by traversing the table *b*, resting the different teeth in succession on the guide finger.

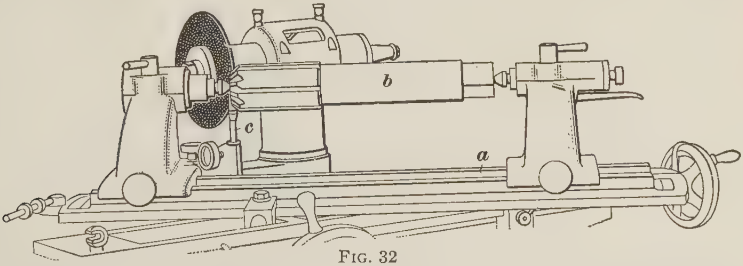


FIG. 32

102. Grinding a Rose Reamer.—The grinding of a rose reamer is illustrated in Fig. 32. As will be noted, the table *a* is swiveled to the desired angle, the reamer *b* is held on the centers of the machine, and the tooth rest *c* is clamped to the table. When grinding, the table is moved lengthwise in the usual way.

103. Mounting Guide Fingers.—Sometimes the guide finger is mounted on the machine table, as shown in Fig. 33, in which case it travels with the work. This method will answer for grinding short work, such as milling cutters less than 1 inch thick and having straight teeth. It is clear that with the guide finger located on the table, it is at rest with respect to the work throughout the grinding; consequently, the work cannot rotate as is absolutely required in the case of tools with helical cutting edges, in order to present every point of each cutting edge to the grinding wheel in exactly the same manner.

104. Generally, a long cutting tool with straight cutting edges cannot be ground correctly with the guide finger fixed with respect to the work. If there was no warping of the tool in hardening this could be done; but after the tool has been hardened, it will be found that however true the grooves were milled, and however carefully the hardening was done, they will have become warped enough to prevent proper sharpening. This can be seen if the tool is first ground to run true, grinding it as if it were a cylinder or a cone. Then, by adjusting the guide finger so as to keep the backing-off slightly away from the cutting edge and taking the cut, it will be found that the land remaining between the cutting edge and the termination of the backing off is not equal in width throughout the length of the tooth; therefore, if the backing off had been carried clear to the cutting edge, the latter would not be true throughout its length.

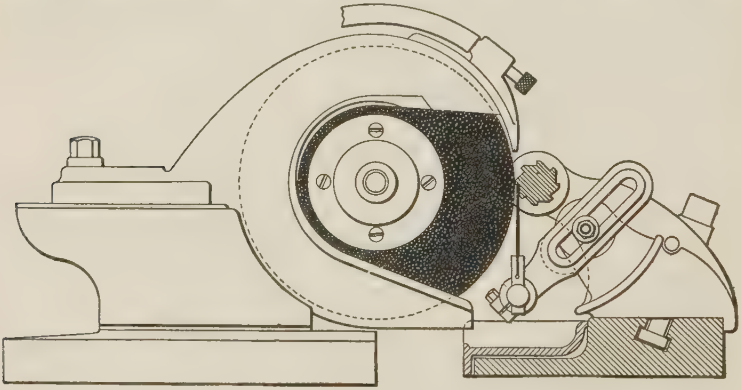


FIG. 33

105. Advantages of Having Wheel Revolve Toward Cutting Edge.—It is desirable that the guide finger be so located that the grinding wheel will revolve toward the cutting edge, and it should always be placed *between* the axes of the grinding wheel and the work, and just as close to the edge that is being ground as circumstances will permit. It should always be applied to the *face* of the tooth, and never to the back, for the reason that any want of truth of the back will affect the truth of the cutting edge. As there is less liability to draw the temper than there would be if the wheel revolved in the opposite direction, it is possible to grind faster by having the grinding wheel revolve toward the cutting edge of the cutter. The tendency to form a burr on the cutting edge is also eliminated by setting in this way. The cutter should always be pressed firmly against the tooth rest by hand; otherwise, the friction of grinding will lift the cutter from the rest.

106. Backing Off.—Cutter and reamer teeth are backed off in a variety of ways. For some classes of work and in the absence of the proper facilities for grinding, the tool is turned to the exact size and fluted, after which it is backed off by filing the proper clearance on the teeth. The cutter or tool is then hardened and is ground by hand on a suitable grinding wheel in order to produce a good cutting edge and a clean surface by which to draw the temper. This method will prove entirely satisfactory for a large variety of comparatively rough work.

107. Several methods of backing off are used, each having its special advantage or use. The teeth of cutters and reamers are left by the machining process somewhat in the form shown in Fig. 34, which is exaggerated for the sake of clearness. In (*a*), a section of a tooth is shown in which *a* is the face, and the land *b* is an arc of the circle forming the circumference of the cutter or tool. With the tooth in this shape, it is of little value as a cutting tool, and can do but very poor work until the land is given proper clearance. The most common form of clearance is shown in Fig. 34 (*b*). A grinding wheel is set so as to grind the back c' of the land away, and the work and grinding wheel are brought together until the edge c is sharp. Obviously, the land will be ground hollow, as shown by the dotted line $c' c$. To leave a well-supported cutting edge, the curvature should be as small as possible; this means that as large a wheel as possible should be used. The amount that the edge c' is nearer the axis of the tool than the cutting edge c, is regulated by adjusting the height of the guide finger.

108. A better form is the straight backing off shown in Fig. 34 (*c*) by the dotted line $e\,e$. This form can be satisfactorily produced only by a cup wheel. Attempts are occasionally made to use an ordinary wheel cutting on its periphery for a straight backing off, setting the machine so that the axis of the wheel is at right angles to the axis of the tool. Such an attempt will result in unsatisfactory work, owing to the wear of the wheel.

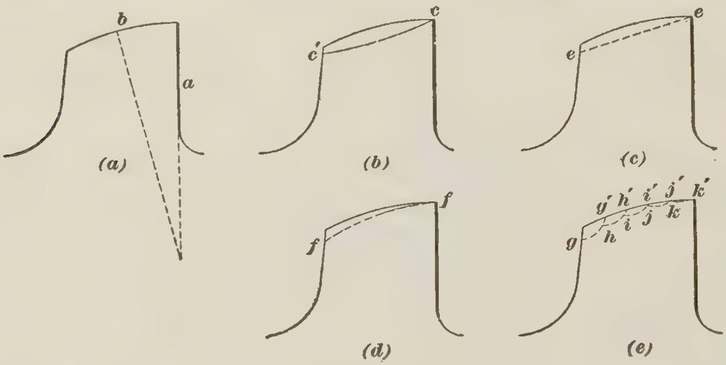


FIG. 34

109. The best form of backing off is shown in Fig. 34 (*d*) by the dotted line $f\,f$, which is the arc of a circle. Unfortunately, this form cannot be produced in the ordinary cutter grinder or universal grinding machine, but requires a machine somewhat similar to that used for making formed cutters. The advantages of this form of backing-off are a well-supported cutting edge combined with ample clearance.

110. In the absence of a special machine, a fair approximation to the form of backing off shown in Fig. 34 (*d*) may be given to a reamer as follows: Set the guide finger so low that the wheel will only touch the back of the tooth, grinding it from *g* to *g*′, Fig. 34 (*e*), and take this cut over all the teeth. Then slightly raise the guide finger and move the work and wheel apart; now again bring the work toward the wheel until it cuts from *h* to *h*′. Continue this cycle of operations until the edge *k*′ is reached. The top of the land will be a succession of ridges that may be smoothed down by careful oilstoning to a very good imitation of the backing off that a special machine will produce. The method just explained is not recommended for any other cutting tools than reamers. In practice, the form of tooth shown in Fig. 34 (*b*) is generally used.

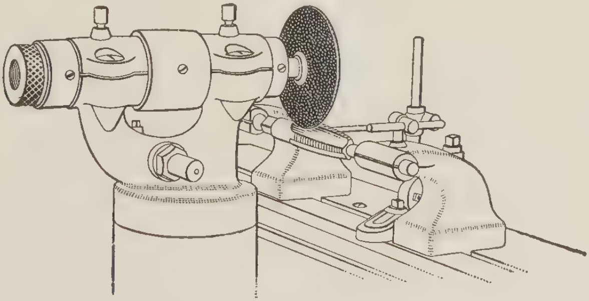


FIG. 35

111. Grinding Taps.—If the flutes in the tap are straight, the tap is ground by mounting it between the centers, as shown in Fig. 35; otherwise, it must be held in a combination attachment, which is tipped the required angle to bring the flutes in the tap parallel with the top of the table. The tap is next brought into the plane of revolution of the grinding wheel, the face of the teeth are brought in contact with the grinding wheel, and the tooth rest is adjusted to the back of the teeth. The tooth rest is clamped to the table in this instance and the cut is taken by moving the table lengthwise. Hobs, formed cutters, etc., are ground in the same way.

GRINDING
(PART 2)

MACHINE GRINDING AND LAPPING

DEVELOPMENT

1. Machine grinding may be defined as the art of producing very accurate plane, cylindrical, and conical surfaces by means of grinding wheels used on automatic grinding machines. Machine grinding differs from hand grinding in that the accuracy of the surfaces produced depends to a great extent on the accuracy of the grinding machine, instead of on the skill of the workman.

In the early attempts made to produce very accurate plane, cylindrical, and conical surfaces, a common emery wheel was mounted on a metal planer or on a lathe; in fact, the first forms of grinding machines for cylindrical and conical work were called *grinding lathes*. These early attempts were far from satisfactory, and many supposed that the errors frequently found in the work were inherent to the grinding process, and could not be eliminated; in other words, grinding was supposed to be incapable of producing true work. Painstaking experiments and a careful study of the conditions convinced the pioneer advocates of machine grinding that the faulty work produced was due to the selection of wheels not adapted to the work expected of them, and to defects in the machinery used. The machinery was gradually improved; its defects overcome; and with wheels selected to suit the work, the grinding machine

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of today can produce work as accurate as can reasonably be expected; in addition to this, it was found that most lines of work could be finished to exact size in much less time than by any other method. The development of grinding is due to the advances made in wheel manufacture, the great precision of grinding machines, the development of very accurate measuring appliances, and the modern manufacturing methods.

2. Classification of Machine-Grinding Operations. The different grinding operations for which a grinding machine is used may be classified according to the position of the surface operated on as *external grinding* and *internal grinding;* or to the character of the surface as *surface grinding*, which term is commonly understood to be an abbreviation for "plane surface" grinding.

3. External grinding may be defined as a grinding operation performed on the outside surface of a solid; **internal grinding,** as the grinding of the surface of a hole. The term **surface grinding** is almost invariably understood to denote the grinding of a plane surface. **Cylindrical grinding,** as implied by the name, denotes the grinding of a cylindrical surface, which may be either an inside or an outside surface. **Conical grinding** is a term that refers to the grinding of tapered work.

CYLINDRICAL AND CONICAL GRINDING

4. Principles.—The fundamental principle underlying the grinding of revolving parts is the application of thousands of cutting points to the surface of the work while it is being slowly revolved about its axis. Each cutting point removes an exceedingly small amount of metal; consequently, the pressure due to the cutting operation is very light. The disturbance of the axes of the work and the wheel is correspondingly small, owing to which the resulting work is exceedingly true.

If the grinding wheel is traversed along the surface of the revolving solid in a *straight* line parallel to the axis of rotation of the solid, the latter will be ground truly cylindrical;

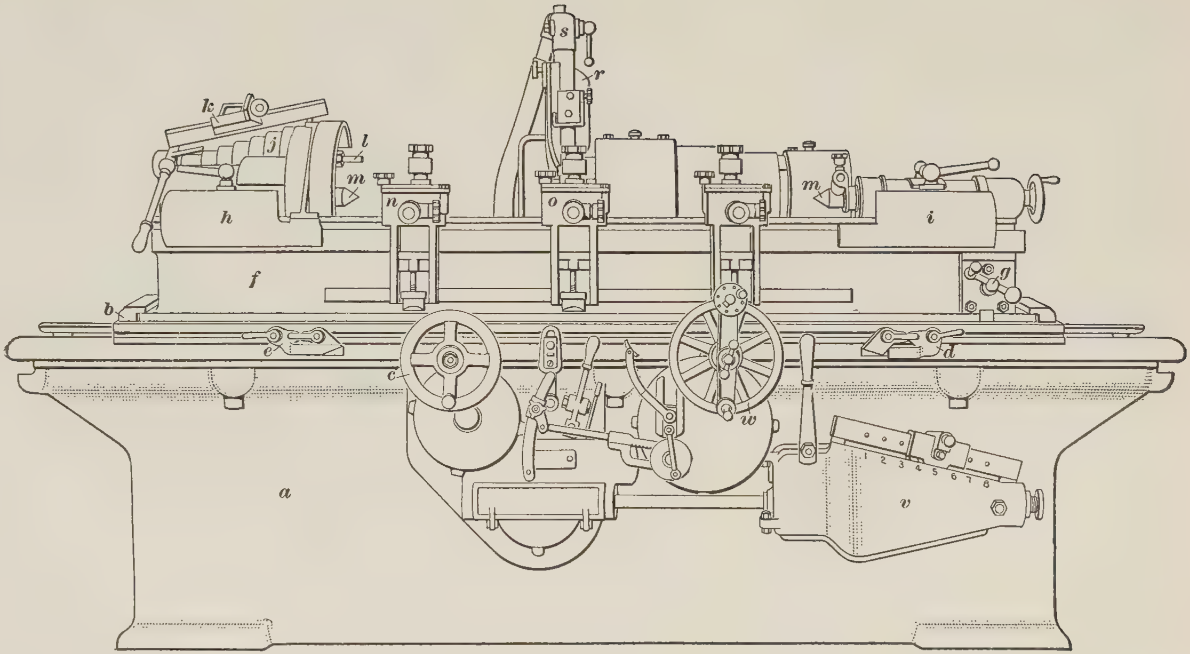


Fig. 1

but if the line of motion of the wheel is at an angle to the axis of rotation of the solid, the latter will be ground conical, or tapered. The grinding wheel may remain stationary, and the work may be traversed past it with the same result.

In practice, the work or the wheel is made to travel in a straight line by mounting either one on a carriage that slides on straight guiding ways that are so designed as to resist wear, and so protected against injury as to remain true as long as the whole machine can reasonably be expected to last without overhauling and repair. In order that a true conical surface may be produced when grinding conical work, it is necessary that the center of the wheel and the work centers be the same height above the ways.

CYLINDRICAL GRINDING MACHINES

5. Kinds of Machines Used.—Both cylindrical and conical grinding is done on what are generally known as cylindrical grinding machines. The kinds of cylindrical grinding machines generally used are *plain grinding machines*, *universal grinding machines*, *chucking grinders*, *internal grinding machines*, and *cylinder-grinding machines*.

6. Construction of Plain Grinding Machines.—The plain grinding machines are designed especially for manufacturing and are made very rigid so as to enable them to do rapid work. They are made with simple adjustments only and with as few joints as possible. This class of machine is intended for grinding plain cylindrical or slightly conical work, such as spindles, rolls, shafts, etc. In all cases the work runs on dead centers—that is, on centers which do not revolve. Fig. 1 shows a front and Fig. 2 a rear view of a plain grinding machine. The entire machine is supported on a rigid base *a*, Fig. 1. The carriage *b* can be moved along the base by the hand wheel *c* or arranged to move back and forth automatically by setting the stops *d* and *e* at the desired places. The table *f* is pivoted on the carriage *b* so that it can be brought parallel to the line of travel or set at a slight angle for grinding tapers. One end of the table *f* is graduated either in degrees or inches per foot,

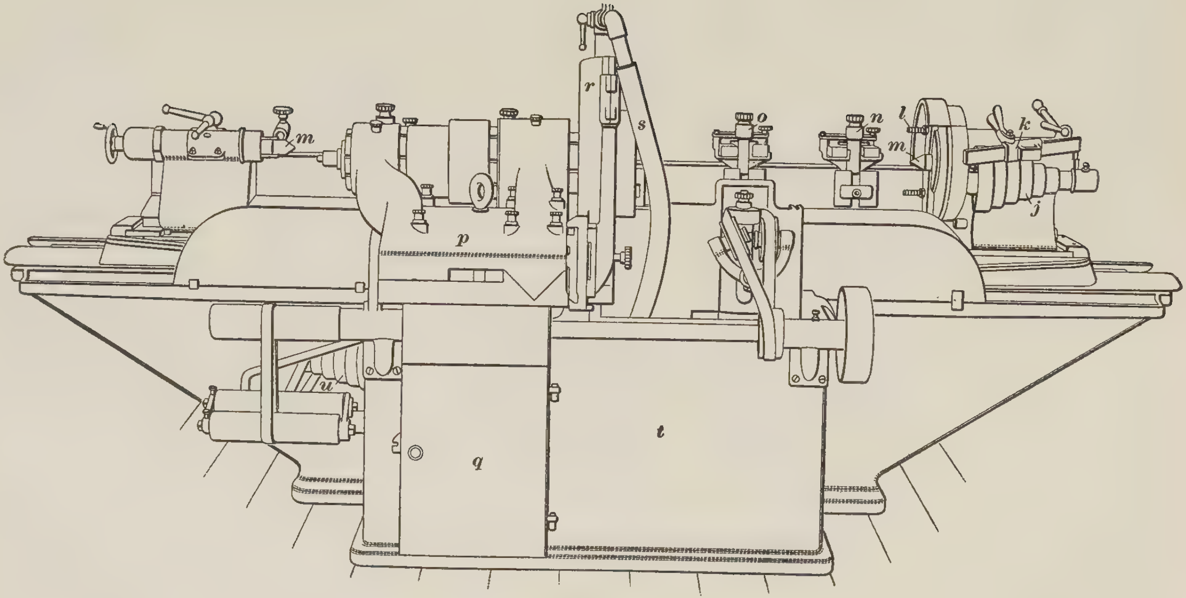


FIG. 2

so as to assist in setting the work to approximately the right position, by the handscrew *g*, the final setting always being made by trial. The headstock *h* and footstock *i* are clamped to the table as shown. The main bearing surface for both the headstock and footstock is made vertical so that it will be protected from abrasive dust and water, without the use of guards that must be adjusted for every change in the length of the work being ground.

7. The cone pulley *j*, Fig. 1, is belt driven from an overhead drum, and drives a set of gears which cause the part supporting the pin *l* to revolve about the headstock center *m*. This pin drives the work, a dog being mounted on the work and in contact with the pin. By means of the belt shifter *k*, the speed of the work is easily adjusted. To assist in supporting the work steady rests at *n* and *o* are used. The grinding wheel is carried upon the grinding-wheel slide *p*, Fig 2, which is well supported from the floor. This slide has a weight attached to it which hangs down behind the door *q*. This removes all danger of the wheel being moved toward the work on account of any vibration. The grinding wheel is provided with a guard *r*, and provision is made for flooding the work with water from the pipe *s*. The water flows back to the tanks *t*, from which it is pumped to the work again. The grinding wheel is driven by a belt from an overhead drum, and provision is made for varying the speed of the wheel by a cone pulley. The table feed is driven by a belt on the cone pulley *u*, which is behind the guard *v*, in Fig. 1.

The grinding wheel and grinding-wheel slide are moved toward or away from the work by means of the hand wheel *w*. An automatic cross-feed mechanism, that will be described later, turns the hand wheel *w*.

8. As previously stated, both the headstock and tailstock centers are dead. Errors in the roundness of the work due to want of roundness in the live spindle are thus eliminated, as well as any errors that might be caused by the live center running out of true. Work ground carefully on dead centers can be reversed end for end and will then run so true that even a very sensitive indicator will fail to show any error. This test is so rigid that work done between centers, where one center is a live one, will very seldom pass it satisfactorily.

In the machine described, the grinding-wheel carriage stands still and the work moves past it. In some machines the table carrying the work stands still and the grinding-wheel carriage moves along the work.

9. Automatic cross-feeds for cylindrical grinding machines are constructed in various ways, but the principle upon which they work is illustrated by the one shown in Fig. 3. This illustration gives the details of the mechanism used on the machine shown in Fig. 1. The length of travel of the table is controlled by the stops *a*, *a′* Fig. 3. The stops *b* and *b′* are usually so set as to reverse the table should it travel beyond either stop *a* or *a′*. The table reversing lever *c* is slotted at the top and carries a slide *d*, which has a pin on its back side, with which the table stops come in contact when reversing the table. The object of the slide *d* is to permit the table to travel past the end of the work without losing the positions of the stops *a* and *a′*. This is done by lifting the slide *d*, which permits the engaging pin to pass over the first stop; but the second stops, *b* and *b′*, are so large that the engaging pin will always come in contact with them, no matter what the position of the slide *d*. The reversing lever *c*, which passes down through the base of the machine and engages with a clutch which reverses the direction of the table travel, is connected through the shaft *e* to the arc *f*. Consequently, the arc *f* is moved by a movement of the lever *c*. The slide *g* moves up and down on the arc *f*, and is held in any position desired by the setscrew *h*.

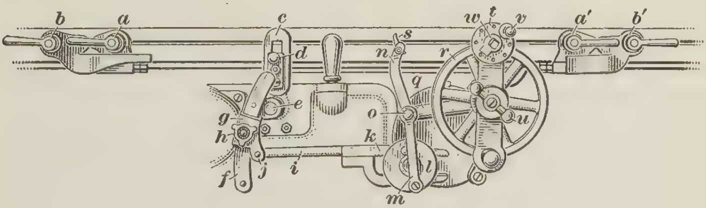


FIG. 3

10. A rod *i*, Fig. 3, is pivoted to *g* at *j* and terminates in a rack *k*, which engages with a gear on the back of the disk *l*. This gear is pivoted so that it is free to move under action of the rack *k* and carries a rod *m* which is connected to a pawl *n* and a second rod *q* at *o*. The rod *q* is also pivoted on the pin which carries the notched wheel *r*. Under working conditions the pawl *n* is dropped against the notched wheel *r*, and it can be seen from the position shown in the figure, that for either a right- or left-hand movement of the reversing lever *c*, the pawl *n* will move up on the notched wheel *r*. The tooth *s* in the pawl *n* is set at such an angle that for an upward movement it trips over the notches in the face of *r*, but on a downward movement the tooth engages in a notch and turns the wheel *r* to the left. The wheel *r* controls the movement of the grinding-wheel slide and turning it to the left advances the grinding wheel.

11. The reversing lever *c*, Fig. 3, as mentioned above, passes through the base of the machine and terminates in a clutch which reverses the table travel. This clutch is driven by two springs that tend to bring the reversing lever *c* to a central position as soon as the table stops have moved away. This would seem to indicate that, when the pawl *n* is moved up on the notched wheel *r* by the table stop acting on the reversing lever *c*, the springs in the clutch act on the lower end of *c* and move it to a central position when the table stop has moved away from the reversing lever. This in turn tends to cause the pawl *n* to give the wheel *r* a slight turn to the left, and the grinding wheel to be fed in while the work is traveling past it. This would make it impossible to grind work straight. However, the friction between the notched wheel *r* and the grinding-wheel slide is enough to prevent the wheel *r* from turning to the left until the work has reached the end of its travel and a table stop again comes in contact with the reversing lever *c*.

12. The disk *t*, Fig. 3, is used for fine adjustment of the grinding wheel and is usually furnished with eight accurately spaced holes, each hole representing .00025 inch. When using this device, the two-balled lever *u* is tightened and the wheel *r*

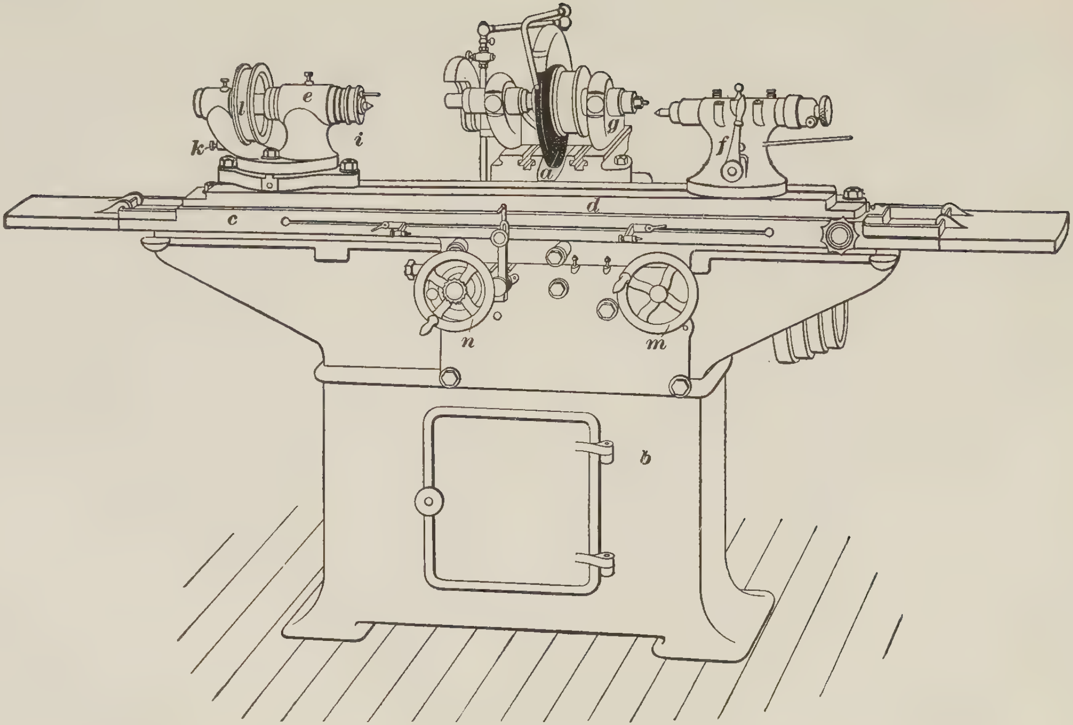


FIG. 4

is operated by means of a small crank *v*. A shield *w* is fastened to the back of *t* and serves to raise the pawl *n* so that the work will not be ground undersize, as follows: After a piece has been ground to size, the wheel *r* is turned, say, three revolutions to the right; thus, moving the grinding wheel back far enough to remove the ground piece and to permit a new piece to be set up. After the next piece is set up, the grinding wheel is advanced by means of the wheel *r* until it begins to cut. The pawl *n* is then dropped against *r*, which will be turned to the left, the number of notches depending on the position of *g* on the arc *f*. When the piece has been reduced to the required size, the shield *w* lifts the pawl *n* so that it has no further action on *r*. If it is found on measurement that the work has not been ground to size, the grinding wheel has worn and the crank *v* is then turned to the right one hole for every .00025 inch the work is oversize. The machine is set in operation again and the work will be found to be down to size when the shield *w* again lifts the pawl *n* from the wheel *r*.

13. Construction of Universal Grinding Machine. A universal grinding machine is shown in Fig. 4. In this machine, the grinding wheel *a* remains stationary during the grinding and the work is traversed past it. The guideways are formed on top of the base *b*, and serve to guide a long carriage *c* to which the table *d* is pivoted. This table carries the headstock *e* and footstock *f*, which can be clamped to it in any position throughout its length. The grinding-wheel stand *g* is mounted on a slide. This stand *g* can be moved along its slide toward or away from the work by turning the wheel *n*. The slide on which the grinding-wheel stand is mounted is pivoted to its base, to which it can be clamped at any angle with the guideways that the construction permits. This allows short conical work having a large included angle to be ground; in that case the table *d* carrying the work will remain stationary while the wheel is traversed past the work. Universal grinding machines are provided with more adjustments than the plain grinding machines, and are adapted for grinding internal and external work, either straight or tapered. They are used to grind smaller and variously formed work, while the plain grinders are used chiefly for large external cylindrical work.

14. The **headstock** in the universal machine has a live spindle to which a chuck or a face plate may be fitted; this live spindle is driven by a belt from an overhead drum. Provision is made for grinding on dead centers by placing a loose pulley *i*, Fig. 4, on which a belt can be put, on the end of the live spindle, for the purpose of rotating the work and providing a suitable arrangement for locking this spindle—in this case, a movable pin *k* that can be inserted into a hole in the pulley *l*. The headstock is placed on a base to which it is pivoted, in order to allow the axis of the live spindle to be placed at any angle with the table that the construction of the machine permits. This adjustment permits conical work held in the chuck or face plate to be ground without disturbing the setting of the table or of the slide carrying the grinding-wheel fixture. The headstock base, bottom of grinding-wheel stand, and end of the table are all provided with graduations, which are used in setting the different parts of the machine to approximately the desired angle for any work in hand. The carriage *c* is moved past the grinding wheel by turning the hand wheel *m*; it is also provided with a feed that can be automatically stopped at any point within the range of motion of the carriage.

15. The headstock is generally arranged so that it can be swiveled; graduations on its base indicate approximately the angle at which the spindle is set to the line of motion; provided, however, that the table itself is set at zero. When grinding work between centers, it is essential to set the headstock to zero; otherwise the graduations on the end of the table will not show the angle between the line of motion and a line joining the centers. When work that is attached to the headstock spindle is ground, the latter is set roughly by the graduations of the headstock; but the final adjustment is obtained by setting the table over.

The adjustment of the table is so simple in all grinding machines that in case the work shows any error due to alinement, the operator finds it more convenient to cure the error by shifting the table than to look for its cause.

16. The **footstock** of a grinding machine serves the same purpose as the tailstock of a lathe, but differs considerably from it in general construction. The footstock spindle of a grinding machine is usually provided with a spring that operates it and regulates the pressure with which its center is pressed into the center of the work. Such a regulation of the pressure contributes, in a large measure, to the accuracy of the work, inasmuch as it prevents springing of the work by an excessive setting up of the footstock center by a careless operator. This spring also maintains a constant pressure on the center, even though there may be considerable wear of the center hole, or the work be lengthened by expansion.

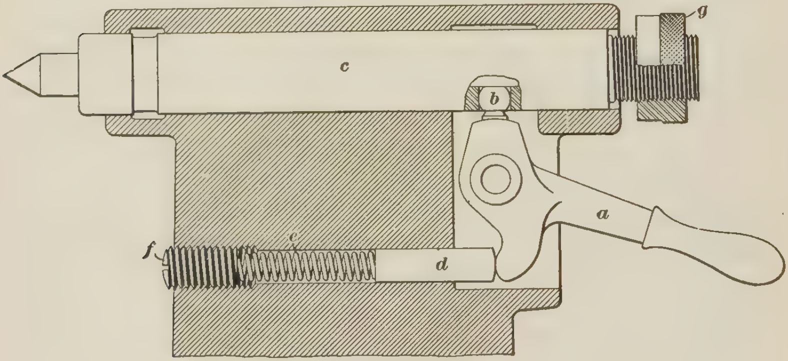
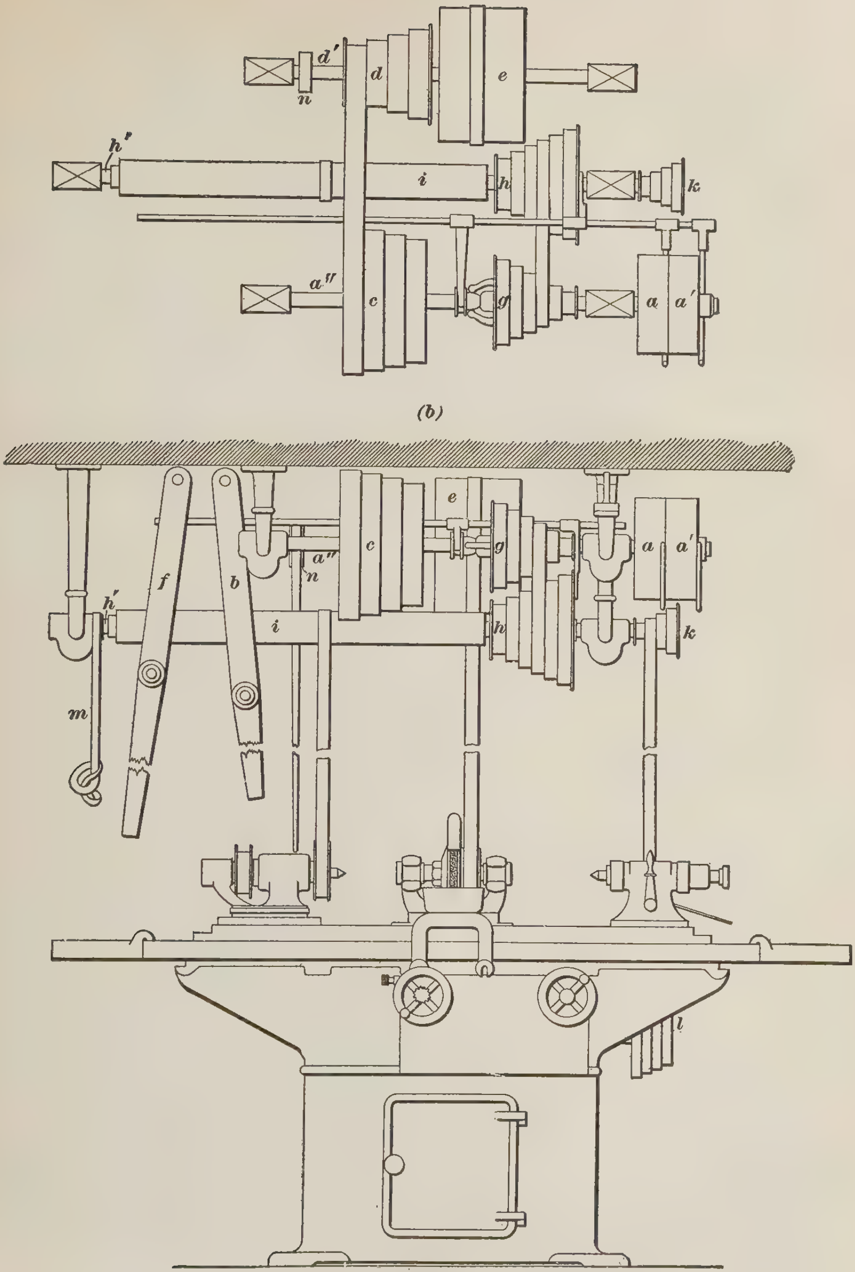


FIG. 5

17. Fig. 5 shows the construction of the footstock of one type of grinding machine. A lever *a* is pivoted to the frame of the footstock; it carries a pin *b* at one end that is placed in a hole cut in the spindle *c*. The lower arm of this lever is acted on by a plunger *d* and a helical spring *e*; this spring tends to move the footstock spindle forwards. The pressure which the footstock center exerts against the work is that caused by the tension of the spring *e*. The tension of this spring can be regulated by means of the adjusting screw *f*. For very small work, even the lowest tension of the spring may cause enough



(b)

(a)

Fig. 6

pressure to bend the work, in which case the pressure may be relieved by screwing the nurled relieving nut *g* against the end of the footstock. The operator must use great care not to turn the relieving nut so much as to loosen the work, which can be told by tightly grasping the work and, while shaking it, observing if there is any end play.

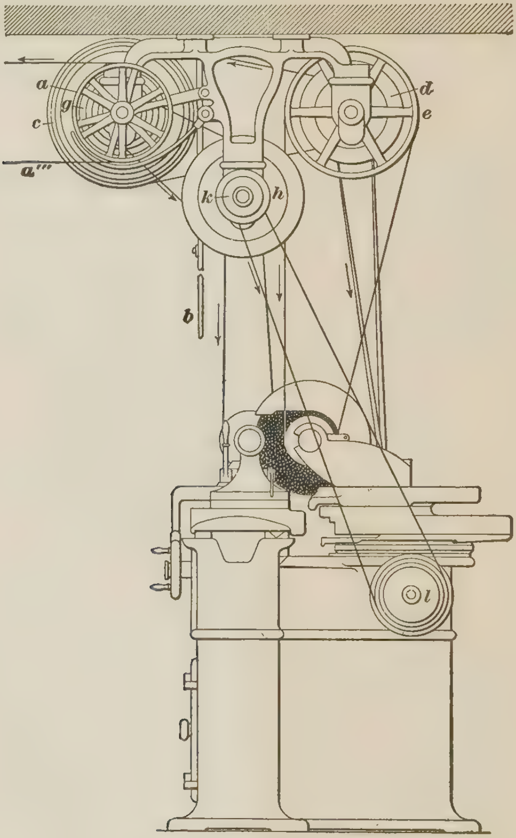


Fig. 7

18. Countershafts for Cylindrical Grinding Machines.—Figs. 6 and 7 show the overhead arrangement of the countershafts for the universal grinding machine illustrated in Fig. 4. Fig. 6 (*a*) is a front view, Fig. 6 (*b*) a plan of the overhead arrangements, and Fig. 7 an end view of the machine. A tight and a loose pulley *a* and *a′* are placed on the countershaft *a″*, which is driven by belting it to a line shaft, and which can be stopped and started by shifting the driving belt *a‴* by means of the shifter *b*. A cone pulley *c* is keyed to the countershaft *a″* and is belted to a cone pulley *d* on the grinding-wheel countershaft *d′*, which carries the cylindrical pulley *e* that is belted to and drives the grinding-wheel shaft. From this arrangement, it follows that the grinding wheel is stopped and started by operating the shifter *b*. A cone pulley *g* is placed on the countershaft *a″*, to which it can be attached by means of a friction clutch operated by the shifter *f*. The cone pulley *g* is belted to a cone pulley *h* on the headstock countershaft *h′*, which carries the long cylindrical drum *i* that is belted to the headstock. Two separate belts are provided to drive the work, one of which is used to grind on dead centers and the other to rotate the headstock spindle for chuck work and face-plate work. The belt that is not in use, as the belt *m* in this case, is removed from the drum and hung up where it is out of the way. The different feeds are driven from the headstock countershaft *h′* by belting the cone pulley *k* to the feed cone pulley *l*. By tracing out the belting, it will be seen that the work will have a direction of rotation opposite to that of the grinding wheel. A rotary force pump is driven by belting it to the pulley *n*.

In any grinding machine, the countershafts must be so arranged that the speeds of the grinding wheel and of the work can be changed independently of each other in order that the best speed may be obtained for each. The changes of speed are usually obtained by placing the belts on different steps of the cone pulleys.

19. Foundation.—The better class of grinding machines are constructed with the view of obtaining satisfactory results irrespective of the level of the floor on which they are used. Machines which grind work up to 10 feet in length are so constructed as to rest on three points of the base and do not need a special foundation. Machines designed to grind work longer than 10 feet are set on a special concrete foundation, since the base of the machine is so long that it would warp out of alinement if the machine were supported on three points.

20. Surface Speeds of Grinding Wheel and Work. The surface speeds of the grinding wheel and the work may be compared with that of the cutting speed of a milling cutter and the feed of the work in a milling machine; since the act of revolving a piece of work in the grinding machine may be likened to the feed of the work in a milling machine, while the cutting points of a grinding wheel may be likened to the cutting edges of a milling cutter.

Suppose that a milling cutter is cutting steel, being run at a surface speed suitable for a proper maintenance of the cutting edges; there is then one particular feed of the work at which the cutter will work at its best, and if this rate of feed is increased too much, the teeth of the cutter will be broken off. If the milling cutter is speeded too high, the heat generated by the cutting operation will be sufficient to draw the temper in the cutting edges, which are consequently rapidly dulled. Also, if the milling cutter is speeded to the proper cutting speed while the work is fed so slowly that the cutter may be said only to rub the work instead of taking a distinct chip, its cutting edges will be rapidly dulled.

21. If the grinding wheel is revolved at the proper speed but the work is revolved too fast, there will be too much stress upon the cutting points or particles of the abrasive material, which, consequently, will break away, thereby rapidly changing the diameter of the wheel and producing a corresponding change in the diameter of the work. In other words, too great a surface speed of the work reduces the diameter of the wheel too rapidly and thus destroys its sizing power.

When run at too high a speed while the work is revolving at a proper speed, the grinding wheel will rapidly become glazed. When run at the proper surface speed, but on work that is revolving too slowly, the grinding wheel will dull rapidly because there is not enough stress on the cutting points to break them, and this dulling will be intensified by the heat that is generated.

When the wheel is run at too low a speed, the speed of grinding is proportionately reduced.

22. For the grinding wheel, a surface speed of 6,000 feet per minute is suitable for hardened steel, cast iron, and chilled iron. For soft steel and other metals except those named, the grinding wheel may be given a surface speed of 7,000 feet per minute. The average surface speed of the work is 30 feet per minute, but it may be considerably higher under certain conditions. For instance, suppose the operator to have a wheel in his machine that was suitable for a job just finished, but which is a little too hard for the new work. In such a case, provided of course that the difference in the grade of the required wheel and the available wheel is not too great, the operator may, by slowing down the speed of the wheel and increasing the speed of the work, get satisfactory results.

23. Selection of Grains and Grades.—The following grains and grades are recommended:

For cast iron, chilled iron, automobile pistons, etc., between $1\frac{1}{2}$ and 4 inches in diameter, grain 24, grade between medium soft and medium; for work over 4 inches in diameter, grain 24, grade a little harder than medium soft; for work less than $1\frac{1}{2}$ inches in diameter, grain 24, grade a little softer than medium.

For machinery steel 6 inches in diameter and smaller, grade a little softer than medium may be used; for work larger than 6 inches in diameter, a little softer grade of wheel should be employed.

When the work comes to the machine with a particularly rough surface—as, for instance, crank-shafts—grades medium and a little harder than medium are used to better advantage than the softer grades.

For pieces made of hardened tool steel, a wheel graded between medium and medium soft is generally used; but if this does not give satisfaction a softer rather than a harder grade should be tried.

24. Chatter Marks.—In machine grinding, the ground surface often has a peculiar wavy appearance to which operators have given the name of *chatter marks*. These marks may be due to a number of different causes, each one of which may act by itself or in conjunction with the others. The most common causes are improperly supported work, looseness of the grinding-wheel spindle in its bearings, and too hard a wheel. Work lacking inherent stiffness should be supported by proper steady rests; a loose grinding-wheel spindle can be cured by tightening the bearings; but a wheel that is too hard is best replaced by a softer one. As a makeshift it is often possible to make a hard wheel cut without chattering by turning down the wheel with a diamond, and so narrowing its cutting surface. But it must be remembered that the amount of work that can be done per minute is lessened, since the quantity of material removed by a grinding wheel depends directly on the width of the cutting surface in contact with the work; therefore, a reduction in the width of the wheel calls for a finer feed.

25. In some cases, the ground surface may have a mottled appearance, or it may be full of ridges that are either parallel to the axis of the work or wind around it like a thread. This appearance of the work is due to any one of a number of causes, such as vibration of the piece, too slow or too fast speeds for the wheel or work, centers not in good contact, inequalities in the stock, work not suitably supported, or a glazed wheel. When a wheel is glazed, there may be one or more spots on its circumference that are sharper than the remainder; these sharp spots may be likened to the cutting edges of a milling cutter that has but few teeth. In consequence, the cutting is intermittent, and the ridges, which may be likened to the revolution marks of a milling cutter, appear. The best remedy is to select a softer wheel.

26. **Feed Lines.**—Spiral lines that are left after cylindrical grinding are termed feed lines. These are caused by the wheel not traveling its exact width at each revolution; or by a wheel that does not run exactly true or cut evenly throughout its width. A different surface effect is thus left on the work where the wheel cuts twice over the same place. Feed lines are a surface effect that produces no measurable difference in diameters.

27. Truing Wheels.—The truing of a grinding wheel is a very important operation, and the quality of the work depends on the care taken when the wheel is trued. A grinding wheel for precision work should be trued with a diamond. A large diamond will be more economical in the long run, as it can be more securely fastened in its holder and the danger of loss is less than with a smaller diamond. Care should be taken to have a full stream of water on the diamond while the wheel is being trued, and to true the wheel by many light cuts rather than with a few heavy ones, because the diamond is heated less under light cuts, and there is less danger of its cracking. Where a large amount must be removed from the wheel, it will be found advantageous to first use an ordinary grinding-wheel dresser and finish up with a few light cuts with the diamond.

Most machines have a socket in connection with the footstock in which the diamond holder can be securely held while truing the wheel. Some operators endeavor to true the wheels by holding the diamond truing tool by hand, resting it on the footstock center during the truing operation. An accurate cutting surface cannot be produced on the wheel by this method. During truing, the wheel should be run at the same speed as in grinding.

28. A wheel must run exactly true and cut evenly throughout its width; otherwise, the wheel may make a cut so rough that it will be pronounced too coarse and unsuitable for the work; while in reality the same wheel if properly trued would produce an even and smooth surface. If the wheel does not cut over its entire surface—that is, if the cutting surface is not parallel to the line of motion—it is impossible to feed at the proper rate without showing feed lines. The beginner will probably attribute these feed lines to too rapid a feed, when in reality they are due to an improperly trued wheel.

29. Circular Truing Device.—Fig. 8 shows a circular truing device by means of which a grinding wheel may be so trued that it will have a straight face and round corners of any desired radius. The device is attached to the center of the footstock and is kept from rotating in the vertical plane by means of the pin *a*, which fits a hole in the footstock. The diamond is held firmly in the end of the rod *b*, which passes through the swinging arm *c*; the rod *b* is held in position by the setscrew *d*. By means of the rod *e*, which can be pushed forwards to set in the groove *f* in the swinging arm, the diamond is kept from rotating should a straight face be required on the wheel. When it is desired to true the corner of the grinding wheel to an accurate radius, the rod *e* is pulled back and the arm *c* is free to revolve about the point *g*. A hole is provided at *g* in which a gauge rod, the gauge end of which is made equal in radius to the desired radius of the corner of the wheel, is placed when setting the diamond; the gauge rod extends upwards, and the gauge end is set at the point directly in front of the diamond. When the rod *b* is set so that the diamond just touches the gauge rod, it will be found that the radius desired will be produced on the corner of the wheel when it is trued. The swinging arm *c* is equipped with ball bearings which are adjustable for wear.

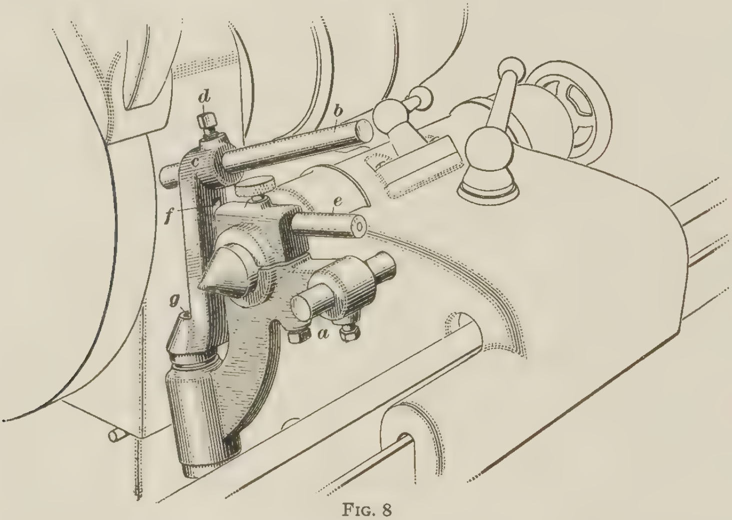


Fig. 8

30. Graduations.—The success of the grinding machine in grinding work accurately to shape—as, for instance, true cylinders or frustums of cones—depends largely on the means for adjusting the line of motion of the grinding wheel or the table in relation to the axis of rotation of the work. These provisions are amply made in the better class of modern grinding machines.

To aid the operator in setting the machine to grind cylindrical or tapering work, one end of the table in all modern grinding machines can be swung around in a horizontal plane, and is graduated to read either to degrees or to tapers in inches per foot. These graduations are intended to assist the operator in setting the table *approximately* to the correct position; for exact grinding, the sensitive adjustment screw with which the table is provided is to be used after it has been determined by measurement where the ground work differs from the desired shape.

31. Setting the Table.—The operator should set the table by the graduations as nearly as can be judged by the eye. It is not necessary to use a magnifying glass. The rough work is now placed in the machine and, by measurement, it is determined which end, if either, is the larger. A very light cut is now taken. If the cut is not heavier at the larger end, as should be the case, the table is carefully adjusted until this desired effect is produced, as will be indicated by the volume of the sparks. The work is now ground evenly and is then measured; but if one end is still too large, the table is adjusted once more and these operations repeated until the work is true.

32. The main reason why the graduations cannot and should not be relied on when accurate work is desired is *not* that the graduations are incorrect, but that any slight warping out of line of the machine, usually caused by changes of temperature, will affect the relative position of the various parts; any error due to this cause will be doubled in the work. Any error in alinement due to unequal wear of the centers will also be doubled in the work. Thus, if one center is .00025 inch out of line in one direction and the other center is the same amount out of line in an opposite direction, the total error in alinement is .0005 inch, and the error of the work will be .001 inch. A slight amount of dirt or oil in the holes in which the centers are placed will cause a corresponding error in alinement.

33. Driving Work Between Centers.—Work ground between centers is driven, as in lathe work, by a dog. The dog used should be as light as possible, especially for slender work, and should be well balanced in order that it will not bend the work during grinding and thus cause poor results. Most grinding machines have a pair of pins set in the face plate, so that a straight-tailed dog having two tails can be used, which is less liable to produce a bending stress on the work at high speeds than the ordinary bent-tailed dog.

34. Steadying Work.—When grinding long and comparatively slender work, it is necessary, just as in lathe work, to use some means to prevent the deflection of the work, owing either to its own weight or to the pressure of the cut. For this purpose a follow rest may be used, or a number of steady rests may be applied to the work.

The benefits derived from a proper application of rests to the work are: the production of a better quality of work; the possibility of taking heavier cuts and the using of a greater speed and rate of feed; and, finally, an increase in the sizing power of the wheel. The term **sizing power** refers to the ability of the wheel to maintain its size for a fair length of time, which enables it to duplicate a large number of pieces without any movement of the wheel slide.

35. Classification of Rests.—The rapidly increasing use and the consequent development of the grinding machine have led to a great number of designs of rests to steady the work while grinding. The different designs divide into two general classes, which may be called *follow rests* and *fixed rests*.

A **follow rest** may be defined as a rest that maintains its position in relation to the wheel; that is, is stationary in respect to it throughout the cut. Such a rest is only adapted to cylindrical work, and for a long time was the only rest supplied to grinding machines.

A **fixed rest,** or **back rest,** now mostly used, is fastened to the table of the grinding machine, and consequently remains fixed with respect to the work. Such a rest is conceded by most operators to be superior to a follow rest, even for straight work. The fixed rest can also be used on tapered work or work having different diameters. Fixed rests may be divided into two subclasses, which are called *rigid fixed rests* and *flexible fixed rests*.

36. Rigid Fixed Rests.—A **rigid fixed rest** is shown in Fig. 9. The frame *a* of the rest is rigidly bolted to the table; a swinging arm *b* is fulcrumed to the upper part of the frame and can be moved slightly by means of the adjusting screw *c*. An adjustable cylindrical plug *d* is carried by the swinging lever, to which it can be clamped by a setscrew. This plug is placed in contact with the bottom of the work, the sensitive adjustment being obtained by the screw *c*, and the rough adjustment, for the diameter of the work, by sliding the plug in the lever. A setscrew *e* is used for steadying the work sidewise.

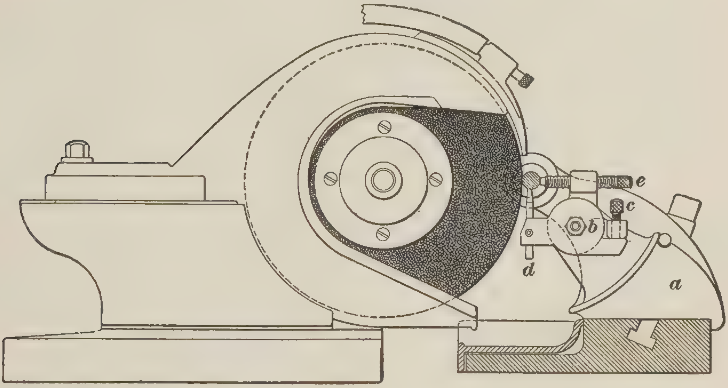


FIG. 9

37. When using a rigid rest, it is not necessary for the operator to spot the work at the place where the rest is applied. The rest is simply applied to the work and grinding commenced. The grinding wheel will cut more from the high side, even though the rest may appear to hold the work so that it runs true, and the work will finally come out round and straight. Care must be exercised in adjusting the parts of a rigid rest, as *d* and *e*, Fig. 9, for a very little pressure will deflect a slender bar, and if the rest is set up too hard, the work may be ground small in the middle. As the diameter of the work is reduced, a rigid rest must be readjusted.

38. Flexible Fixed Rests.—The simplest of the various forms of flexible fixed rests is the so-called **spring rest** shown in Fig. 10. The frame *a* is fastened to the table of the machine; it has a rectangular recess at the top into which the rectangular shank of the shoe *b* is so fitted as to move easily. The end of the shoe that bears against the work is curved to suit its diameter; the rear end of the shoe is acted upon by a helical spring *c* whose tension can be adjusted by means of the thumbscrew *d*. The shoe should be made of some soft material, as brass, Babbitt, or wood. This kind of a rest reduces or eliminates the vibration of the work by reason of the inertia of the shoe and the tension of the spring *c*; it is open to the objection, however, that too great a tension of the spring will cause the work to be bent. On the other hand, the spring will cause the shoe to follow up automatically any reasonable reduction in the diameter of the work. The shoe should never be made of any hard material, as it should wear rapidly to a good fit, since the value of the shoe in absorbing vibrations depends largely on the degree of its contact with the work.

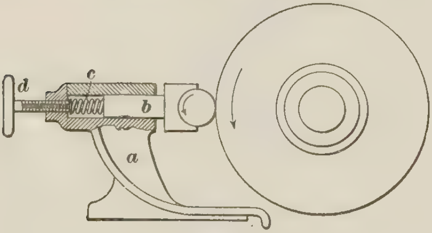


Fig. 10

39. One type of flexible fixed rest, known as a **universal back rest,** for a plain grinding machine, is shown in Fig. 11. The back rest for universal machines works on the same principle, but is constructed quite differently. The frame *a* is clamped to the table of the machine by turning the nut *a*′. A swinging lever *b* is pivoted to the frame at *c*; a spring *d*, whose tension can be adjusted by the thumbnut *e*, tends to force the upper end of *b* toward the work. The extent to which the lever can move toward the work is regulated by the thumbscrew *f*, whose end, by coming in contact with a shoulder *g* of the frame, limits the motion of *b*. The shoe-carrying frame *h* is hinged to the upper end of the lever *b*, and the front end of *h* rests on a part of the frame *a*. This construction allows the frame *h* to move toward the work to the extent permitted by the position of the screw *f*, but does not permit the front end of *h* to drop. The shoe *i* has trunnions, as *i′*, which rest in **V** notches formed at the front end of *h*. The shoe is held against the work by a helical spring *k*, whose tension is adjusted by the thumbnut *l*. The spring *k* bears against the movable nut *m*, which carries the adjusting screw *n*, the end of which

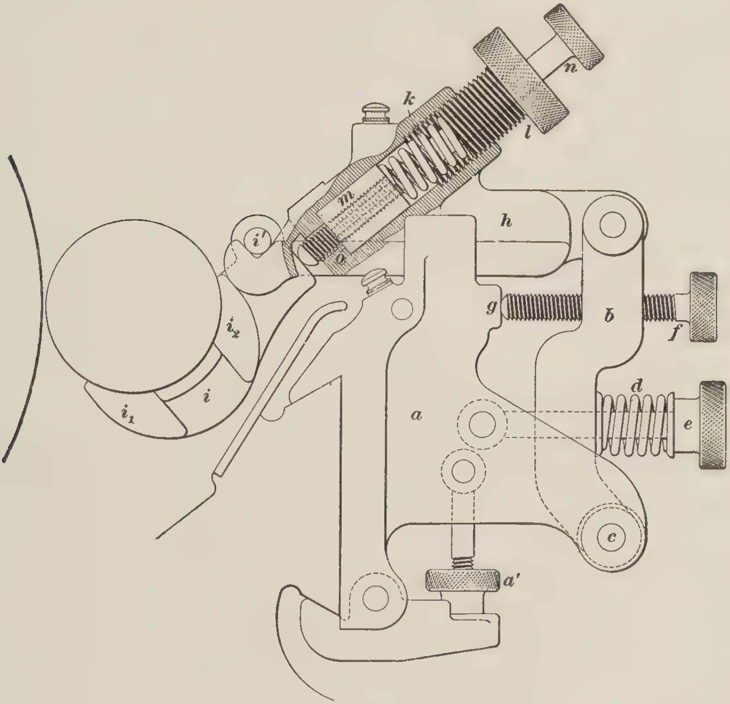


Fig. 11

bears against the shoe. The action of the spring *k*, therefore, causes a rotation of the shoe *i* about *i'*, thus tending to draw the part i_1 of the shoe against the work. The screw *n* passes through a clearance hole in the thumbnut *l*, and its axial motion under the action of the spring *k* is limited by the lower face of the nut *m* coming against a shoulder *o* of the shoe-carrying frame.

40. The part i_2, Fig. 11, of the shoe is held against the work by the spring *d*, while i_1 is held against the work by the spring *k*. The pressure of the shoe against the work can be arrested at a predetermined diameter by a proper adjustment of *m* and *f* in respect to the shoulders *g* and *o*. If these adjustments are properly made, it is impossible for the springs to bend the work. Different sizes of shoes will be required for different diameters of the work; since the shoes are removed by simply lifting them out of the **V**'s in the frame *h*, they are readily changed.

Since the shoe is operated by spring pressure in two directions at right angles to each other, it can yield to suit the inequalities of unground work, and hence there is no necessity of grinding the work to run true at the place where the rest is applied, prior to the application.

41. Absorption of Vibration.—When comparatively stiff work that is being ground without a rest commences to vibrate, as occurs occasionally, the vibrations can sometimes be absorbed by holding a block of wood against the work by hand, resting one end of the block on the table. This is only a makeshift to be used where single pieces are being ground. In doing commercial work, a rest should always be used. Whenever a piece of work or a wheel commences to vibrate, the cause should be ascertained and the proper remedy applied. The vibration may be caused by a glazed wheel, improper speed of wheel or work, or irregularities in the stock. For very small work the wheel face must be narrow to avoid vibration.

42. Special Rests.—Where a large number of duplicate pieces are to be ground, special rests can often be advantageously used. These rests must usually be of the fixed-rest type, and may be rigid rests or spring rests. Their design rarely presents any difficulties, as they are generally but simple modifications of the rests here described, the modification having been made necessary by the shape of the work.

43. Local Heating and Its Prevention.—In cylindrical grinding the work and the wheel are flooded with water for the purpose of carrying away the heat generated by the grinding operation. The work is thus kept at a temperature that is uniform enough to prevent a sensible change in the outline of the work.

Any one who has done lathe work knows how hot the work becomes under the influence of the cutting operation; and as in grinding, the cutting is done much more rapidly, and, besides, by a great number of cutting points, the local heating of the work at the place where the grinding is being done is more pronounced. Even if the rise in temperature is so slight that the bare hand cannot detect it, a local heating of any piece of work will cause a greater change in the outline of the piece than is ordinarily supposed. This change in outline becomes very apparent in a grinding machine, in which under proper conditions a grinding wheel is capable of showing an error as small as .000005 inch, the error becoming apparent by the increase or diminution of the sparks coming from the wheel when cutting.

44. A thin stream of water was first used for **lubrication in grinding,** the main idea being to carry away the heat of the grinding operation. As grinding practice advanced it was seen that a supply of lubricant—usually water containing alkali which prevents rusting—sometimes about 40 gallons a minute should be applied directly at the point of grinding, not so much to carry away the heat of the grinding operation as to keep the temperature uniform throughout the piece being ground. The face of the grinding wheel will also be kept much cleaner under a large flow of water than otherwise.

45. The influence of **local heating** on the quality of the work is well shown when an attempt is made to grind dry a slender cylindrical piece of steel between centers. As the grinding wheel passes back and forth over the work, the operator will notice that sometimes the wheel is grinding more on one side of the work than on the other, and at other times, it will grind on one side only. Passing over the work again, the wheel may cut on the opposite side, then it may cut at right angles to where it last cut, and so on. No matter how long the grinding continues, the cylinder will not become round.

46. The following considerations explain why the work does not become round: When a round bar or piece of steel is held in the hands and a point about midway between its ends pressed against a grinding wheel, the grinding will cause a local heating at the point in contact with the wheel, and consequently the side of the bar that is toward the wheel will elongate, thus causing the ends of the bar to curve away from the wheel. Now assume that the bar of steel is placed between centers in a grinding machine, and that the wheel is again cutting midway between the ends. Then, as in the previous case, the side of the bar in contact with the grinding wheel will elongate; but as the ends cannot curve away from the wheel, since they are held by the centers, the middle of the bar will curve *toward* the wheel. The fact that the bar may be revolving does not alter the case, since the point where the grinding is taking place is always hotter than the opposite side of the bar. If the wheel is passed back and forth over the bar, the side of the bar where the sparks show will be constantly elongated, and if the piece being ground is entirely free from internal stresses and of absolutely uniform density, it will be ground round, but smallest at the middle. Unfortunately, the ideal condition of a piece of work free from internal stresses and of uniform density does not occur in practice; and, in consequence, the elongation of the bar will not be uniform throughout each revolution. Hence, the bar will bend a varying amount toward the wheel, and as this is still further varied by the additional heat due to the increased depth of cut, owing to greater elongation at certain points, the result is a bar that is neither round nor straight.

The remedy for the troubles due to change of temperature is simple: flood the work with sufficient water to maintain a uniform temperature and use a suitable wheel.

47. Sparks an Indication of Accuracy in Grinding. The relation between the depth of the cut and the volume of sparks can only be studied in actual grinding by noting the volume of sparks emanating from a grinding wheel for a given movement of the wheel slide, as indicated by the dial of the adjusting screw. From this relation, an experienced operator can estimate closely the accuracy with which work is being ground. The amount of metal that is removed when sparks are just visible has been ascertained. A hardened steel plug gauge about 1 inch in diameter was very carefully ground in an accurate machine by allowing the grinding wheel to pass back and forth until sparks had ceased to show. The size of the plug was then carefully determined in an accurate measuring machine and it was again placed in the grinding machine. The grinding wheel was very carefully moved toward the work until sparks just became visible and was then passed back and forth until no sparks could be seen. By carefully measuring the work again it was found that the piece had been reduced .00001 inch in diameter, which showed that the depth of cut was only .000005 inch.

48. Allowances for Cylindrical Grinding.—In making allowances for finishing by grinding, the amount of stock to be removed and the method of preparing the work for its removal are very important factors. The allowance to be made for this finishing is dependent on many things—the type of machine employed, the skill of the operator, and whether or not the piece has been hardened. The usual allowance is from $\frac{1}{32}$ to $\frac{1}{64}$ inch. The larger amount is generally conceded for hardened work, which will probably be more or less distorted by the process of hardening. Too large an amount must not be left for grinding if the work has been case hardened, or the hardened surface may be ground away by the finishing cut.

When the work is turned before grinding it is not necessary to turn to a smooth finish. It should be remembered that the grinding machine is the finishing tool and not the lathe, and the greatest economy can be obtained by rough-turning preparatory to grinding.

49. Roughing and Finishing Cuts.—During the roughing cut, when the wheel is removing stock rapidly, a coarse surface is produced and chatter marks are sometimes noticeable. Provided this rough surface does not go too deep it has no detrimental effect on the finishing cuts. Between the roughing and the finishing cut, the grinding wheel must be carefully trued, in order to obtain a perfect and smooth finish on the work. The surface produced on the work is directly dependent upon the care used in truing the wheel. The work is always revolved slower when finishing than when roughing.

Except for light finishing cuts, satisfactory work will not be obtained with a wheel, the face of which is formed to the desired shape of the finished piece, for the reason that the wear of a grinding wheel will soon cause some parts of a formed wheel face to lose their shape and the piece will not be ground to the form desired.

50. In order to produce a very fine finish, it would at first seem that a wheel of very fine grain must be used. However, for cast iron, chilled iron, and specially hardened steel, a very coarse wheel will produce a very fine finish, provided the grade, the depth of cut, the speed of work and the speed of wheel are correct, and the wheel has been very carefully trued with the diamond. Should an ordinary dresser have been used instead of the diamond, a rough surface on the work will result, as a dresser leaves a very rough surface on the wheel; that is, the wheel scratches instead of grinding to a smooth finish.

For brass, bronze, and softer metals the size of grain in the wheel should be as fine as the finish desired. Manganese and phosphor bronzes are considerably harder than the ordinary run of bronzes, and the required surface can be produced with a coarser wheel than on the softer materials.

The finish on cylindrical work is quite commonly tested by rubbing the surface with a piece of lead, which has been bent to fit. This method is often misleading, as the lead will follow the inaccuracies in the piece ground to a certain extent. The best method of testing the finish on a cylindrical piece of work is to lap it with a tight fitting ring. Even this method is some-

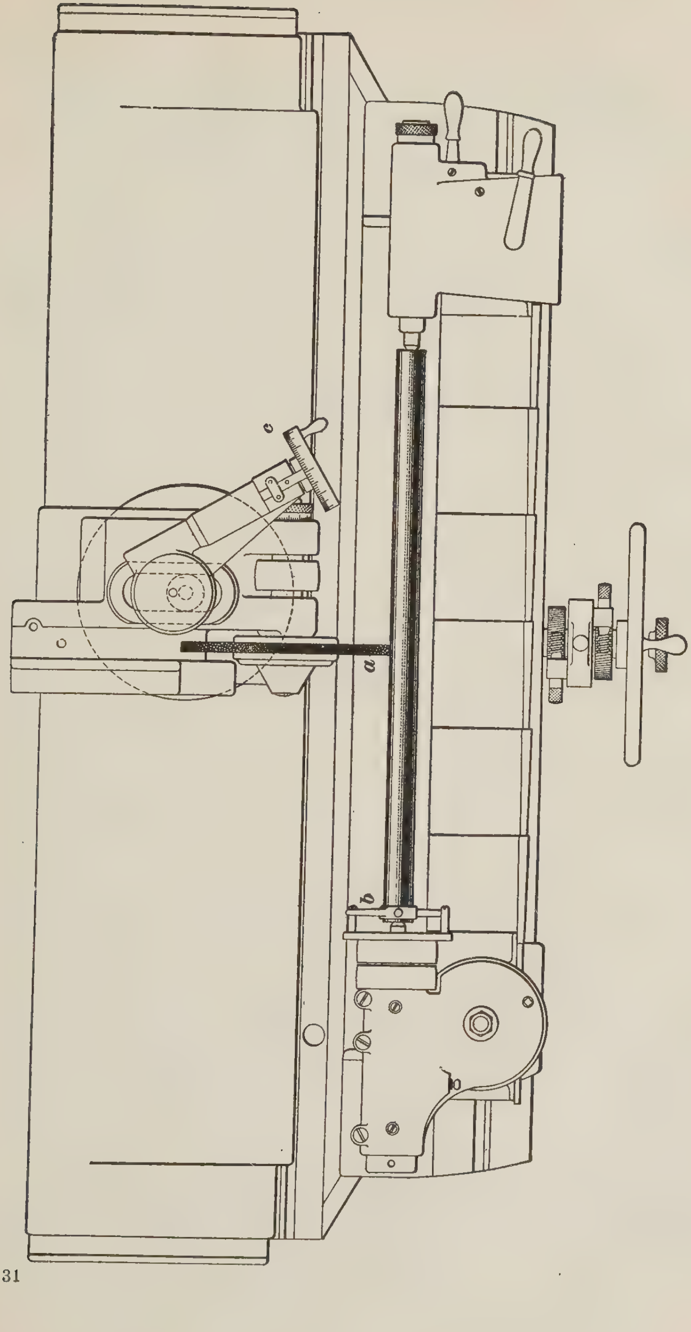


Fig. 12

times misleading, as it will show up mottles or waves which often are so shallow that they cannot be measured with ordinary instruments and for all practical purposes are negligible.

EXTERNAL GRINDING

51. A good idea of the kind of work that can be done in a grinding machine can be obtained by an examination of the following examples of external grinding. These examples will serve to show how the machine may be arranged and what shape of wheel may be used to advantage. The lessons conveyed by them will suggest ways and means of doing work different from that shown.

52. Grinding a Cylindrical Rod.—Fig. 12 shows one of the simplest grinding jobs—the grinding of a cylindrical rod between centers. The illustration is a top view of a machine on which the table is stationary and the wheel moves past the work. The wheel *a* is set at right angles to the line of motion, so that its cutting surface is cylindrical. In order to grind the work cylindrical, the line of motion of the wheel must be parallel to the axis of rotation of the work, and this condition is obtained by shifting the table until trial shows the work to be cylindrical. The table is shifted by a taper adjustment handle, not shown in Fig. 12, similar to the handle *g* in Fig. 1. The illustration shows the manner of driving the work by means of a dog *b* having two tails that balance each other, though in practice only one of them is in contact with a driving pin. It would be commercially impossible to grind the piece shown without using a number of steady rests; but they are not shown, as they would only complicate the illustration. The wheel is moved toward or away from the work by adjusting the hand wheel *c*, which is graduated so that the amount the wheel is moved can be told at a glance.

53. Facing a Bushing.—In Fig. 13 is shown how a bushing may be faced square. The bushing *c* is placed on a true-running mandrel that is put between the centers and is driven by a dog. In order that the grinding wheel may pass clear over the end of the bushing, the end *a* of the mandrel should be turned down somewhat smaller than the part fitting the bushing; the latter is then placed on the mandrel so that the face that is to be ground projects somewhat from the shoulder at *b*. Since the grinding must be done by the side of the wheel, the latter should be recessed as shown, leaving only a narrow surface to do the cutting. The wheel is fed against the face in the direction of the axis of the work; this will generally give a better face than feeding the wheel back and forth across the face of the work.

54. Grinding Conical Work.—The grinding of a short frustum of a cone is shown in Fig. 14. The included angle being beyond that attainable by swinging the table *a*; it is obtained by swiveling the lower wheel slide *b* until it makes the required angle to the axis of rotation of the work, the table *a* first having been set to zero, however, in order that the graduations on *b* may give a correct indication. The upper wheel slide *c* is set at right angles to *b* to allow a square-faced wheel to be used. It will be observed that the slides *b* and *c* form what may be called a compound rest. If the frustum of a cone that is being ground must be very exact, its accuracy will probably be tested by a gauge; the final adjustment for the angle is then made by swiveling the table *a* by means of the adjusting screw provided for the purpose.

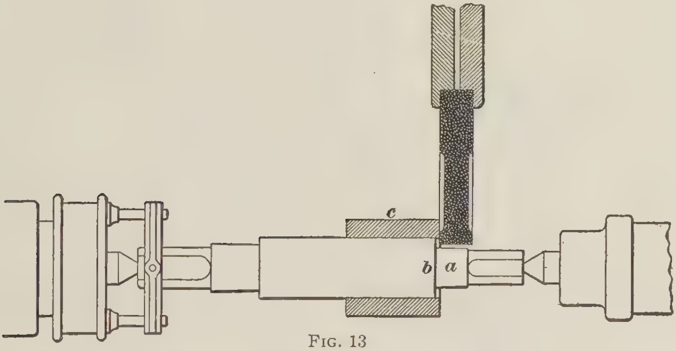


FIG. 13

55. In Fig. 15 is shown how a piece of work having two different conical parts may be ground, where one of the parts is within the range of angles that can be obtained by swiveling

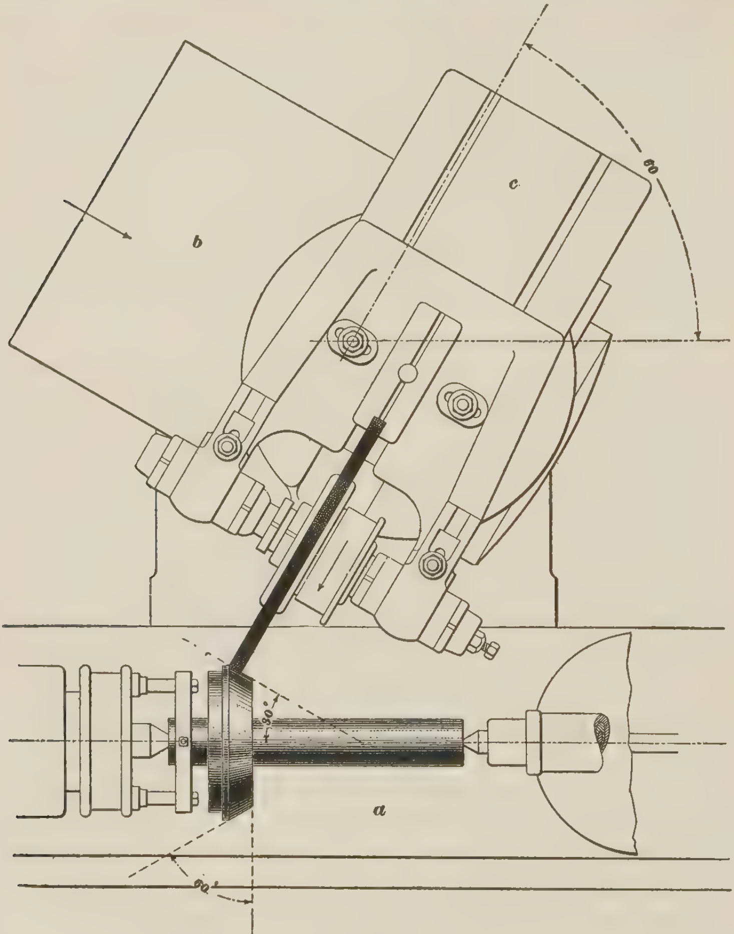


Fig. 14

the table *a*. Thus, the conical part *b* is ground with the table set over, while the conical part *c* is ground by setting the lower wheel slide *d* to an angle to suit the required angle. The wheel carriage is traveled past the work as in ordinary cylindrical

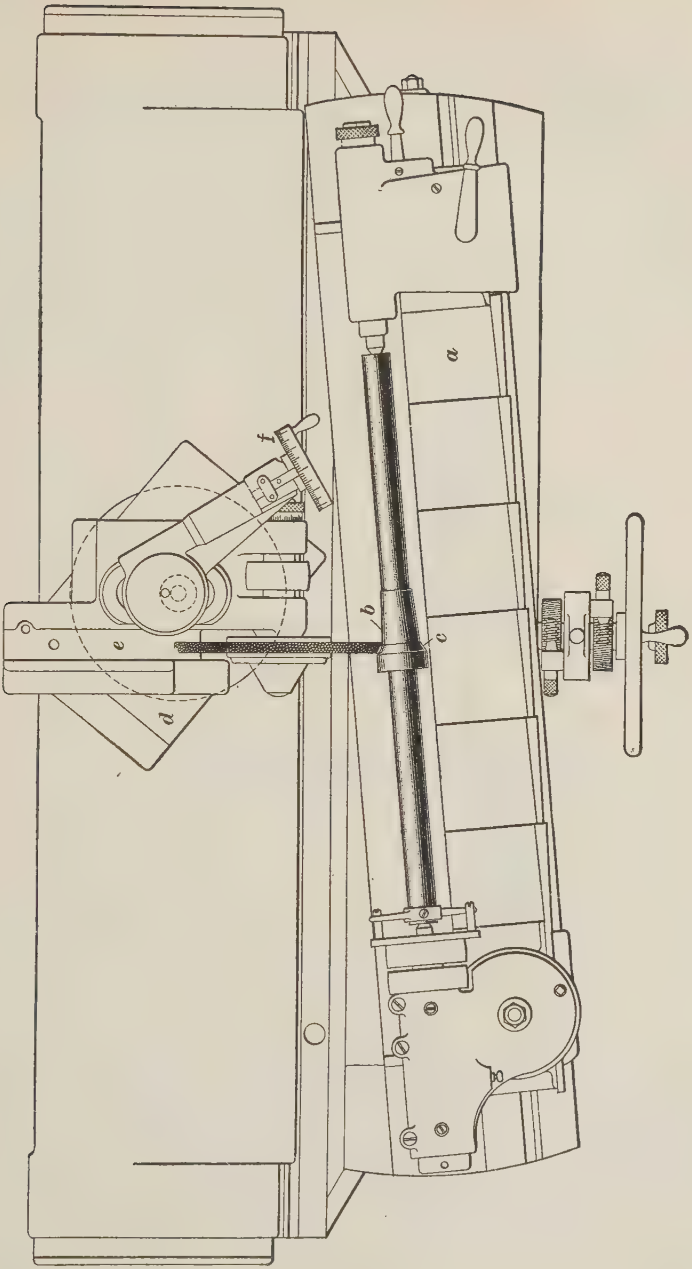


FIG. 15

grinding, while the conical surface *b* is being ground; but to grind the surface *c*, the wheel carriage remains stationary and the wheel head is moved by turning the hand wheel *f*, along the lower wheel slide *d*, in the direction of the surface to be ground. The graduations on *d* will not indicate the angle of *c*, since the table *a* is not at zero. One edge of the grinding wheel is beveled to suit the conical part *c*. The wheel is adjusted for depth of cut by moving it along the upper wheel slide *e*.

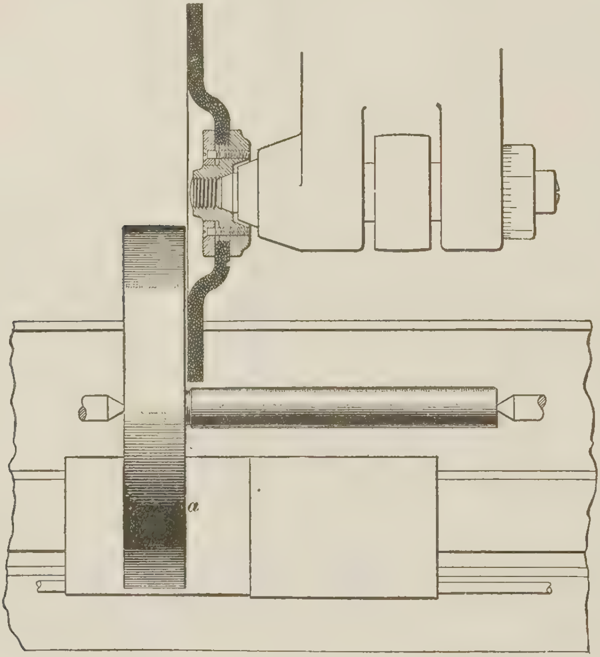


FIG. 16

When a number of pieces like that shown in Fig. 15 are to be ground, the sensitive adjustment of the table can only be used for the conical part *b*. The final adjustment for *c* must be obtained by shifting the lower slide *d*. As long a piece as the one shown could not be ground without the use of steady rests.

56. Grinding Close to Shoulder.—An example of grinding a shaft close to a large shoulder is shown in Fig. 16.

In this case, the ordinary flat wheel cannot be used, since the nut and the washers employed for fastening it to the spindle will come in contact with the shoulder of the work while the wheel is yet some distance from the shoulder. The dished wheel shown in the illustration is therefore employed. Such a wheel should not be used for grinding the face *a* of the shoulder, owing to the large grinding surface that will be in contact with the work. The wheel cannot clear itself of the particles of metal, and if the shoulder requires grinding, it is better to recess the wheel in order to narrow the grinding surface.

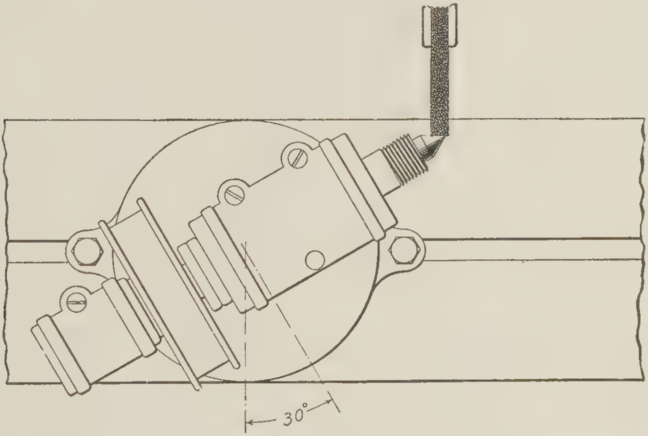


FIG. 17

57. Truing Centers.—Fig. 17 shows how the centers may be trued in a universal grinding machine by swinging the headstock around to make an angle of 30° with the line of motion, in order that the centers may be ground to the American standard angle of 60°. In all modern grinding machines, the headstock center and tailstock center interchange, so that both centers may be trued in the headstock spindle. In plain grinding machines, where the headstock cannot be swiveled, the centers are trued by means of a special fixture that is only a supplementary headstock that is removed from the machine after the centers are ground. Obviously, the center must rotate during grinding.

58. Chuck Work and Face-Plate Work.—The manner of using a universal grinding machine for chuck work and face-plate work is shown in Fig. 18. When the work is to be ground to a plane surface, the headstock is placed exactly at right angles to the line of motion of the table or grinding wheel, the table first having been set to zero. The final adjustment is obtained by means of the sensitive adjustment with which the table is supplied, taking trial cuts over the work and testing it with a straightedge. For conical work the headstock is swiveled to the required angle.

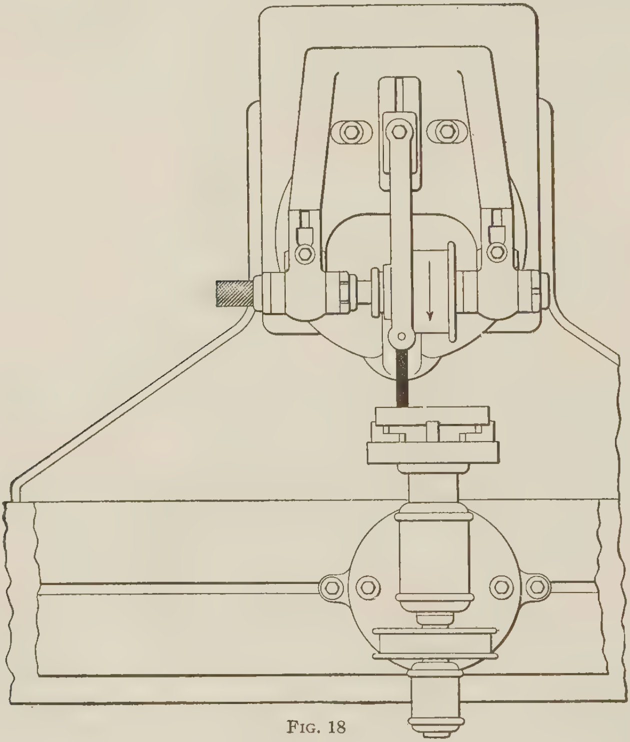


Fig. 18

59. Special Chucks.—Thin saws, milling cutters, and similar work that either cannot very readily be held in the chuck or that cannot be attached to a face plate because the clamping devices are in the way of the grinding wheel, can often be successfully held for grinding by means of the special chuck shown in Fig. 19, the use of which presupposes that the work has a fair-sized round hole whose axis is at right

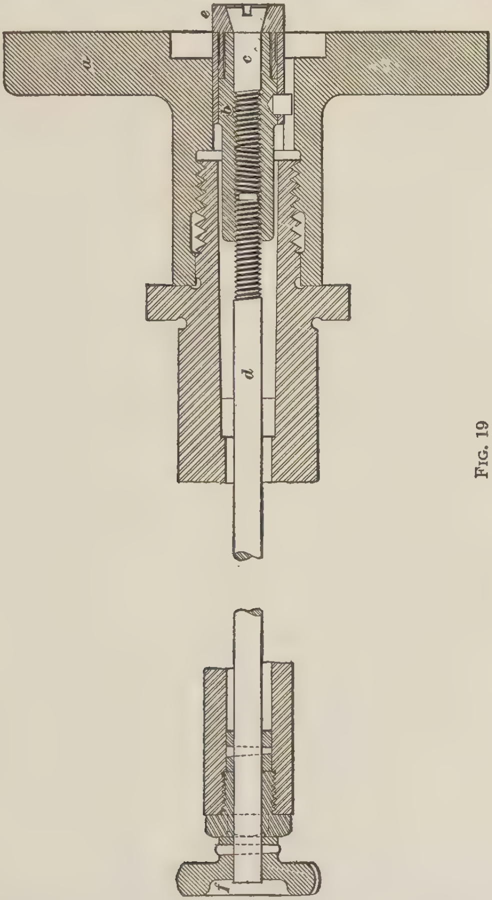


FIG. 19

angles to the face that is to be ground. A face plate *a* is screwed to the headstock spindle. A sleeve *b* that is threaded on the inside to fit the screws *c* and *d* is nicely fitted to the central hole of the face plate; this sleeve is movable lengthwise and is kept from turning by a pin that works in a longitudinal slot of the face plate. The front end of the sleeve *b* is arranged to take the shank of the bushing *e*, the projecting part of which is fitted to the hole in the work. The bushing *e* is split so that it can be expanded to grip the work tightly by turning the conically headed screw *c*. When this has been done, the work is drawn against the face plate by turning the small hand wheel *f*, which is keyed to the screw *d*. A separate bushing will be required for each size of hole.

60. Set-Wheel Method.—When a large number of duplicate pieces of simple form are to be ground, grinding-machine operators usually employ the so-called set-wheel method of grinding. In this method, all the pieces are first roughed out to within a small limit of the finished size, say, .001 inch, and then all are finished. The operator first sets the grinding wheel, by trial, to the roughing size, and then, without moving the wheel slide, grinds all the pieces to the roughing size, measuring the work from time to time and moving the wheel toward the work to make up for the wear of the wheel. When all the pieces have been roughed out, the wheel is set, by trial, to grind the work to the finished size, and piece after piece is put into the machine and finished without disturbing the setting of the wheel, except to compensate for the wear.

For the set-wheel method, a wheel should be selected that will not wear very rapidly; and after all the pieces are roughed out, the wheel should be carefully trued by means of a diamond tool. It will then produce a smooth and even surface on the light finishing cut, although the surfaces produced on the heavy roughing cuts may have been rather coarse.

61. Grinding Crank-Shafts.—By modern methods of manufacture, automobile crank-shafts are often ground from the rough forging on the grinding machine. The first operation consists of roughing down to within $\frac{1}{32}$ inch of size. Because lathe tools cannot be properly supported to take a deep cut, in automobile crank-shaft turning, the grinding machine can successfully compete with, and remove material faster than, the lathe, in this class of work.

The fillets are formed at the same time that the stock is being removed from the shaft. This is accomplished by using a wheel having round corners, which may be made to the proper curvature by means of a circular truing device, using a diamond.

62. Good all-around wheels for grinding crank-shafts are grain 24, grade one degree harder than medium, vitrified for roughing; and grain 24, grade medium, vitrified for finishing. The finishing wheel is always ordered $\frac{1}{32}$ inch wider than the length of the pin or bearing to be ground. If the crank-pin is $2\frac{1}{4}$ inches in length, the wheel would then be ordered $2\frac{9}{32}$ inches wide. The object of the extra thickness in the finishing wheel is to allow for truing off the sides of the wheel, in order that it may run perfectly true when grinding the bearings.

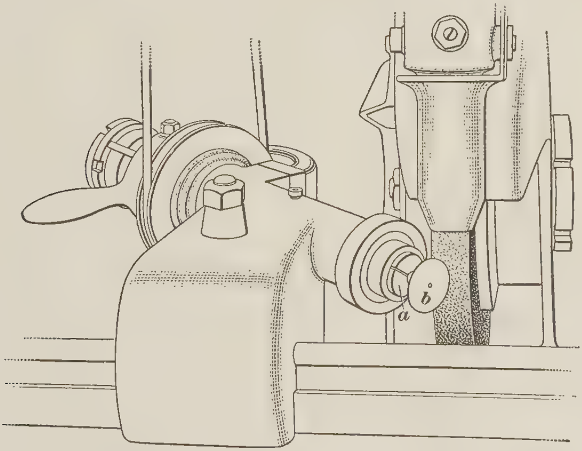


FIG. 20

63. Valve-Grinding Attachment.—In Fig. 20 is shown a valve-grinding attachment to be used in connection with a cylindrical grinding machine. This device makes use of a draw-in chuck *a* to hold the stem of the valve *b* while the face of the valve is being ground. The principal use of the device is for grinding the faces of valves for automobiles and other gas engines. An attachment of this kind is very carefully made, all

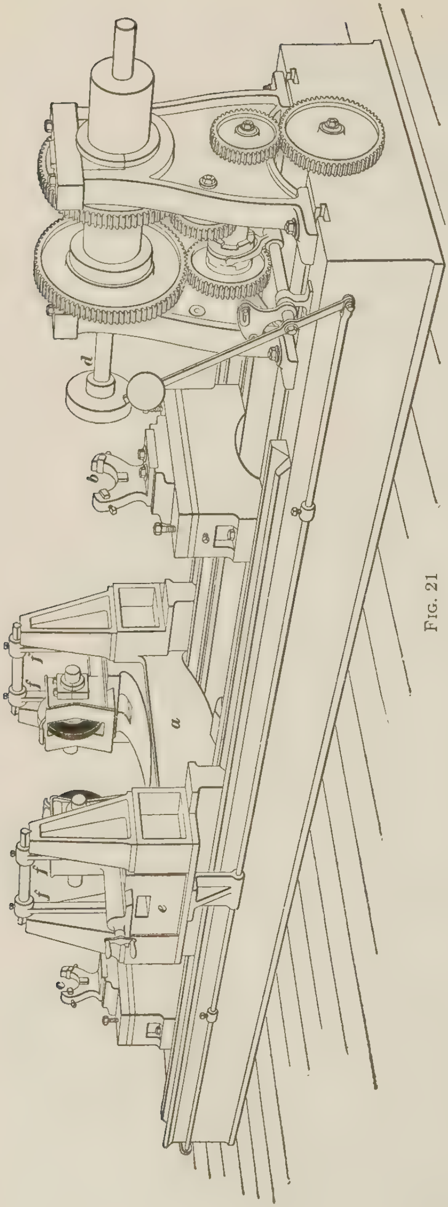


FIG. 21

the revolving parts being hardened and then ground. In using this attachment, the stems of the valves must be finished to within a limit of .001 inch to insure accurate grinding of the face. The particular device shown in Fig. 20 is for valves, the faces of which have angles of 45°; but attachments are made by means of which it is possible to grind any angle from 30° to 60° on the face of the valve.

64. Poole Method of Cylindrical Grinding. — As is well known, a round bar may show under very refined measurements as being exactly round and of uniform diameter, and may yet be far from straight; that is, it may be far from a true cylinder. In all ordinary grinding machines, the straightness of the work depends primarily on the straightness of the guiding ways that determine the line of motion of the wheel or the work, and while the work may be round in spite of error of the guiding ways, any such error is certain to produce work that is not straight. While it is not a very difficult matter to produce straight guiding ways in small grinding machines intended for comparatively light work, the problem becomes more difficult when a machine suitable for the grinding of such work as the calender rolls used in paper making is to be constructed. Such rolls are quite large and must be exceedingly straight and uniform in diameter. J. Morton Poole devised a special method of grinding that largely overcomes any reasonable error that would be induced by want of straightness of the guiding ways. In the Poole method of grinding, the periphery of the grinding wheel is kept at a constant distance from the axis of rotation of the work, not by the straightness of the guiding ways, but by gravity.

65. Fig. 21 is a perspective view of the machine, which in some respects resembles a lathe with the tailstock left off. The carriage *a* that carries the grinding wheels is mounted on **V**'s, along which it can be traversed. The roll that is to be finished has its two journals ground perfectly true and these journals are placed in the jaws of the steady rests *b* and *c*. The jaws of these rests are of the same height above the guiding ways. The work is driven from the headstock spindle *d* by means of a flexible connection, in order that any want of alinement between the axes of rotation of the work and the spindle may not disturb the former during grinding. Two grinding wheels, each mounted on its own wheel slide, are used on opposite sides of the work. The two slides work in a heavy casting *e* that forms their base; this casting is supported by four links *f*, from the top of the carriage by means of knife-edge bearings. This construction allows the grinding wheels to swing freely in a direction at right angles to the axis of rotation of the work, and the wheels will obviously be at rest when the center of gravity of the whole swinging part occupies its lowest position.

66. The distance between the grinding wheels during each cut being constant, it follows that the roll being ground will be of uniform diameter throughout, neglecting here the wear of the grinding wheels which will be exceedingly small during a light finishing cut. Any one who doubts that a bar may be apparently round and of uniform diameter without being straight, should bend a straight piece of drill rod, which, as supplied by manufacturers, is quite round and exceedingly uniform in diameter. With a reasonable amount of bending the piece will caliper the same throughout its length. While the diameter and also the roundness of the piece are doubtless changed by the bending, the change is so slight, when the bend is not excessive, as to be insensible.

67. Assume that the roll being ground is not exactly straight. Then, when revolved in the steady rests *b* and *c*, it will run out of true, and the high side coming toward one of the grinding wheels will tend to push over the swinging frame. This tendency is resisted by the weight of the swinging frame, and, consequently, there is a pressure. dependent on the amount that the roll runs out of true, that causes the wheels to alternately cut away the high side until the center of gravity of the swinging frame returns to its lowest position, when the wheel ceases to cut. It will be understood that the frame swings back and forth as the high side of the revolving roll engages one or the other of the two grinding wheels. By repeated passages of the carriage along the bed, the roll is finally so ground as to run perfectly true; and as the fixed distance between the wheels insures a uniform diameter, the finished roll becomes a very close approach to a perfect cylinder, independently of the truth of the guiding ways. In practice, the operator takes most or all of the swing out of the carriage while roughing the roll. On the whole, this is a rather slow process, though it produces very good work. Some classes of rolls have to be ground large or small in the middle. This may be done by raising or lowering the swinging carriage at the proper points so as to bring the wheels above or below the center of the roll. As soon as the wheels are raised above the center of the work they will grind large.

INTERNAL GRINDING

68. Influence of Pressure.—In internal grinding the truth of the surfaces, at least as far as the grinding itself is concerned, depends primarily on the amount of pressure caused by the grinding operation. As in external work, this pressure disturbs the position of the work, and, since the amount of disturbance depends directly on the pressure, it follows that a reduction of the pressure to the lowest limit attainable with a given set of conditions, causes a corresponding reduction of errors and a consequent increase in the truth of the work.

69. The pressure required to make the wheel cut is always greater in internal grinding than in external grinding, especially when the hole that is being ground is small. This is due to the greater contact of the grinding wheel with the surface of the work; the extent of this contact will become apparent when a grinding wheel but slightly smaller than the hole is employed. For equal depths of cut, equal diameters of wheels, equal diameters of the work, and equal widths of the wheels, the extent of the wheel in contact with the work will always be greater in internal grinding than in external grinding. This is shown in Fig. 22, where a cylinder *a* and a cylindrical ring *b* having the same diameter of the surface to be ground, are illustrated. The grinding wheels *c* and *d* have the same diameter, and both are set for the same depth of

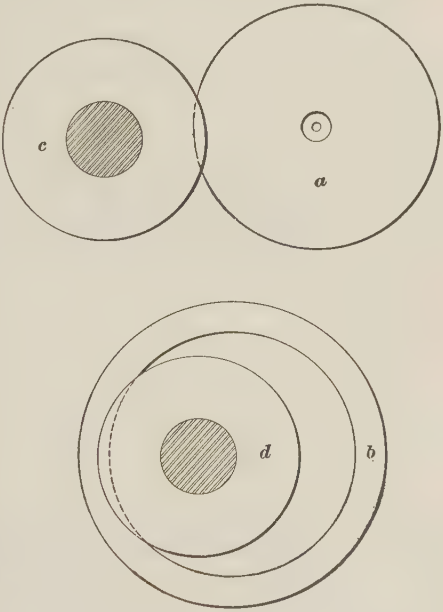


FIG. 22

cut. The surface with which the wheel is in contact being greatest in internal grinding, it can be readily understood that the pressure of the cutting operation will be greater than in external grinding. The conclusion may readily be drawn that in order to reduce the pressure of the cut, the depth should be much less in internal than in external grinding.

70. Influence of Speed.—The grinding wheel obviously must be smaller than the hole in which it is to be used. To obtain the best cutting speed, the wheel would have to be run at a very high number of revolutions per minute. For example, to obtain a surface speed of 7,000 feet per minute with a wheel whose diameter is $\frac{1}{2}$ inch, the spindle must make 53,476 revolutions per minute. The spindles cannot be run much higher than 60,000 revolutions per minute; a specially designed spindle is essential to sustain this speed day in and day out and produce straight cylindrical holes.

When a grinding wheel is run at a surface speed below its best cutting speed, more pressure will be required to make it cut; but as the required pressure is less with a soft wheel than with a hard one, a softer wheel should be used whenever circumstances prevent the attainment of a proper surface speed. Since this condition exists usually in internal grinding, much softer wheels should be used than for external grinding, in order to reduce the pressure.

71. Considerations Affecting Stiffness of Spindle.—In external grinding, the spindle that carries the grinding wheel can always be made as stiff as may be desired; but in internal grinding the size of the hole that is to be ground determines the maximum diameter of the spindle. If the hole is small and deep, the spindle must be correspondingly small and slender; consequently, it will yield to a certain extent under a very moderate pressure. Hence, in order to reduce the deflection of the spindle, it should be as large as circumstances will permit, and be supported close to the grinding wheel.

72. In the earliest designs of internal-grinding fixtures, a spindle of as large diameter as possible was employed, and the distance from the wheel to the nearest support was at least equal to the depth of hole to be ground; but while the requisite stiffness was obtained, another serious error was introduced. This error was due to the looseness of the spindle in its bearings, which is necessary for free running, but which shows much greater at the end of the spindle by reason of the long distance between the wheel and the nearest bearing. The consequent wabbling of the wheel caused it to follow the imperfections of the hole being ground and prevented the grinding of a true hole.

73. Internal Grinding Fixtures.—An internal grinding fixture is shown in Fig. 23. In this fixture the spindle is kept as stiff as those previously used, and, in addition, the bearing is so designed that no wabbling of the wheel may occur. The grinding wheel *a* is carried by the spindle *b*, which has a long journal working in a split-bronze bearing *c*. The spindle is held in place lengthwise by the collar *d*, which bears against the end of *c* on one side, and on the other side bears against the end of the tube *e*. The outside of the bearing *c* is tapered and fits the tapering bore of the supporting shell *f*. The wear of the bearing is taken up by screwing the tube *e* into the shell, thus causing the bearing to close. The tube *e* is then slightly unscrewed to give the collar *d* a free running fit. The end of the spindle is splined and fits loosely in a central hole of the driving shaft *g*, which carries the driving pulley *h*. Two pins *i* and *j* engage the splined end of the spindle and cause it to turn with the driving shaft. The outer shell *f* and the end of the

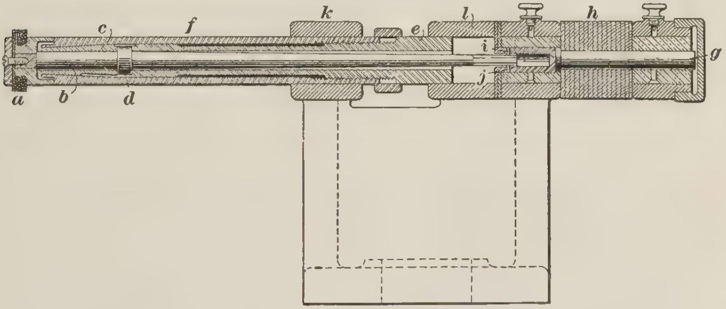


FIG. 23

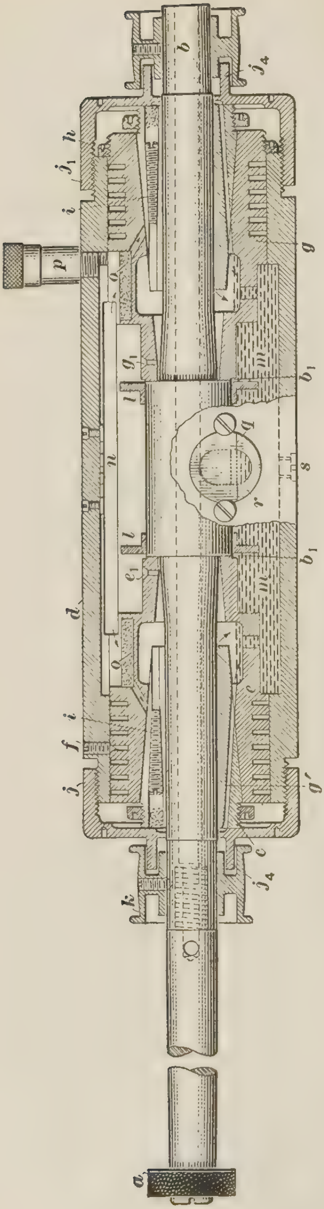


FIG. 24

tube *e* are sliding fits in the bearings *k* and *l*, and *f* can be clamped to *k*. The wheel *a* may thus be brought somewhat closer to the bearing *k* when grinding shallow holes.

74. Another form of internal grinding fixture is shown in Fig. 24. The grinding wheel *a* is carried by the spindle *b*, which has long journals working in split-bronze bearings *c*. In the front end of the casing *d* is inserted a fixed bearing holder *e*, secured by a setscrew *f*; and in the opposite end a bearing holder *g*, whose position may be adjusted by the threaded adjusting collar *h*. The endwise adjustment of the spindle is obtained by the inner ends of these bearing holders which come in contact with the shoulders b_1. The bushings *c* are adjusted by the taper adjusting screws *i*, and the threaded caps *j* and j_1 bring pressure against the ends of the bushings, holding the parts firmly in place. The projections j_4 on the caps enter recesses in the pulleys *k* at the ends of the fixture, and serve to protect the spindle and bearings from abrasive and dust.

Two flanges *l* on the spindle enter an oil reservoir *m*, and, when revolving, throw the oil to the walls and roof of the casing. A long trough *n* receives a portion of this oil and conducts it to the felt filtering pads *o*; it then flows through passageways to the bearings and spindle as indicated by the arrows, and back to the reservoir. Part of the oil passes through the holes e_1 and g_1 and floods the bearings. The oil is supplied through the cup *p* and should be kept to the level of the line *q*; the height of the oil may be seen through the sight glass *r*. To empty the reservoir, the screw *s* is removed. The pulleys are connected by belts to obtain the desired speed.

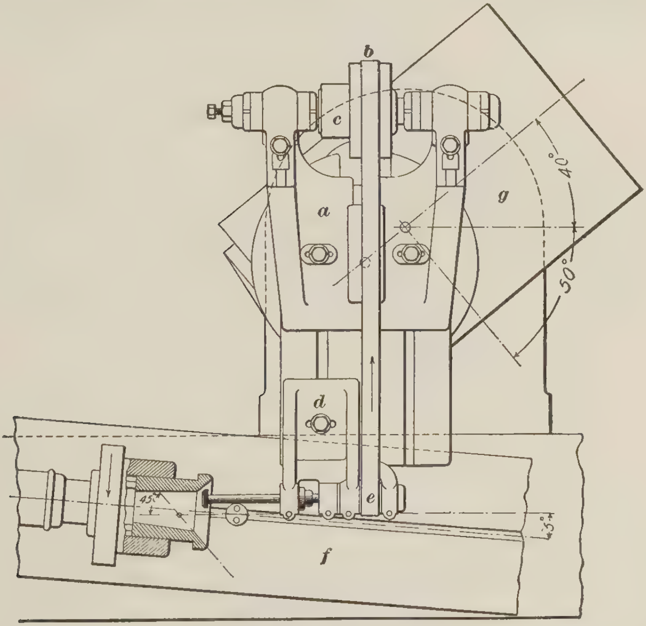


FIG. 25

75. Driving the Spindle.—The method of driving the spindle for internal grinding, where a fixture having only one pulley is used, is shown in Fig. 25. The grinding wheel is removed from the wheel stand *a* and a driving pulley *b* is put in its place. The wheel stand *a* is then reversed, so that it occupies the position shown in the illustration. The pulley *c* is now belted to the drum overhead. The internal-grinding fixture *d* is bolted to the wheel slide; its spindle is then driven by belting its driving pulley *e* to the pulley *b*. Special machines are constructed to use the fixture shown in Fig. 24, although this fixture may be used on any machine to which it may be belted.

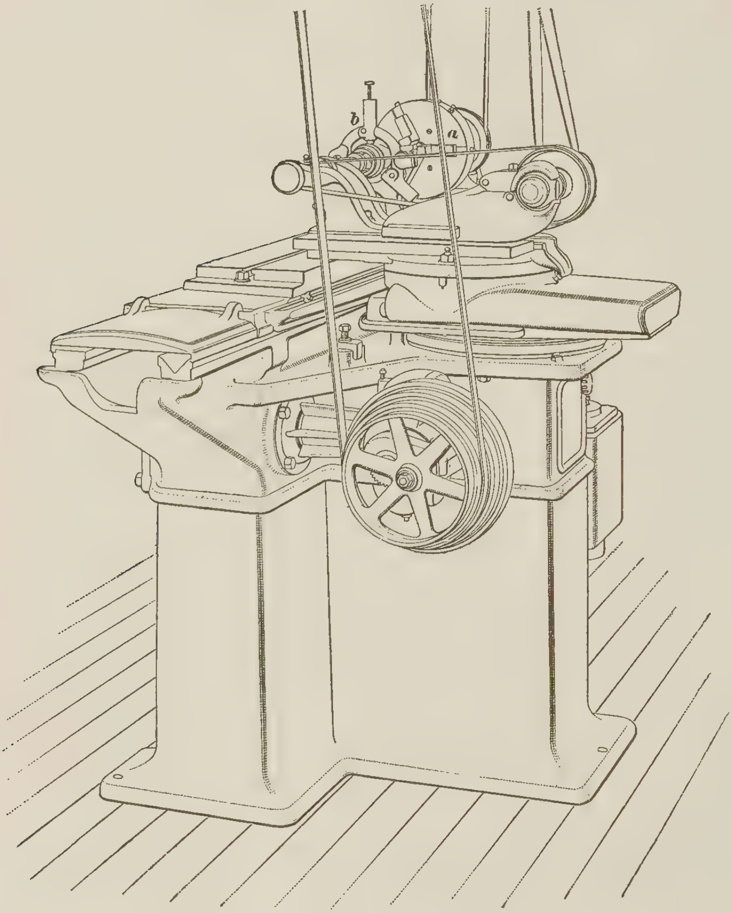


Fig. 26

76. Grinding Conical Work.—Fig. 25 shows how the universal machine is used for grinding a hole having a double taper; that is, whose surfaces form frustums of two different cones. The table *f* is swung around to grind the smaller taper, and the wheel slide *g* is set over in order to grind the larger taper. When the machine has a swivel headstock, one taper may be ground by setting over the headstock, leaving the table at zero. The other taper is then ground by setting over the wheel slide, or changing the setting of the headstock.

77. Fig. 26 shows how a tapering hole in the end of a spindle may be ground to run true with the outside. One end of the spindle is held in the independent jaw chuck *a*, while the other end is run in the center rest *b*. For testing the truth of the end of the spindle that is held in the chuck, a sensitive indicator should be used, the operator revolving the headstock spindle by hand and truing the work until the indicator shows it to run dead true. The center rest insures that the other end of the spindle runs true. The proper taper is obtained by setting over the table. When adjusting the center rest, great care must be taken that the work is not thrown out of alinement with the axis of rotation of the headstock spindle, for if this is done, the jaws of the chuck will badly mar the end of the work, and besides the work is likely to creep slowly forwards in the direction of its length during the grinding. The jaws of the center rest should touch the outside of the work just enough to prevent any shaking. If they are set up too tight, the work will heat very rapidly, and

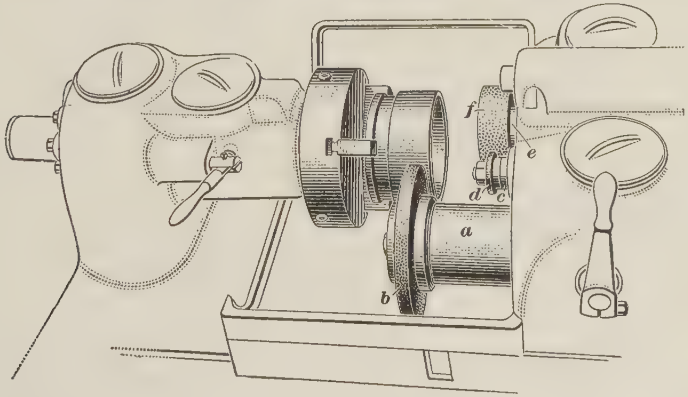


Fig. 27

since it expands with the heat, it will cause a still greater pressure on the ends of the jaws, which may score the work.

78. Chucking Grinders.—A type of grinding machine in which the work is held in a chuck, and which is known as a *chucking grinder*, is shown in Fig. 27. In this machine three different grinding wheel spindles are employed. The spindle *a* carries a grinding wheel *b*, which is used for grinding the outside of the work; the spindle *c* carries the wheel *d*, which is employed for grinding the inside of the work; and the spindle *e* carries the wheel *f*, which is used for facing the work. All the spindles have a motion lengthwise, and the carriage has a crosswise motion. Provision is made to revolve the carriage toward the operator, thus making it easier to insert and remove the work. The spindles, carriage, and feeds are operated by handles and wheels not shown.

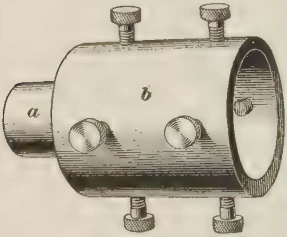


FIG. 28

79. Chucks.—For grinding machines, universal chucks are not to be recommended, because they will not hold the work true enough for the purpose. Independent jaw chucks are preferable in every respect, since they not only allow the work to be trued carefully, but also frequently permit hardened work having a small grinding allowance to be trued to suit the warping caused by the hardening process. If such work is held in a universal chuck, it will often be impossible to finish it to size with the given grinding allowance, owing to the error in the chuck itself and the inability to true the work to suit the warping.

80. A shell or thin cylinder cannot always be trued sufficiently in the ordinary independent jaw chuck. In that case a so-called **bell chuck** may be used. This form has the advantage over the jawed chuck in that it allows both ends of the work to be trued independently of each other. Such a chuck is shown in perspective in Fig. 28. The end *a* is threaded to fit the headstock spindle; the body *b* is bored sufficiently large and deep to freely admit the work, and eight thumbscrews, six of which are shown, are used to hold the work and adjust it so that it will run true.

81. In Fig. 29 is shown a form of **chuck for holding gears** when grinding the holes *a*. The pieces *b* are attached to the jaws *c* of the spring chuck which is operated by the hand wheel *d*. Contact between the pieces *b* and the gear takes place between the ends of the teeth on *b* and the bottom of the tooth spaces on the gear.

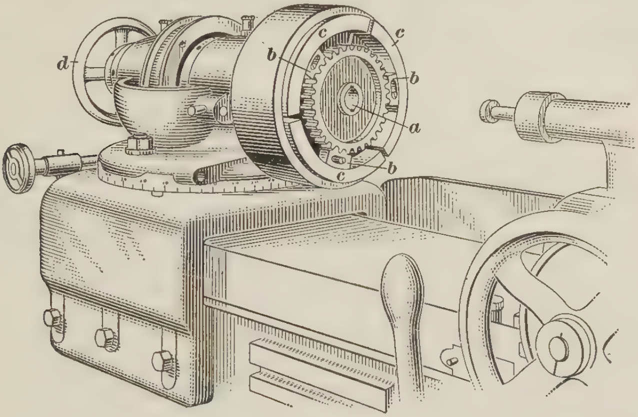


Fig. 29

In Fig. 30 is shown a **chuck for holding long sleeves** with thick walls when doing internal grinding. The centering of the sleeve *a* is done by the bevel collar *b* in the back part of the chuck, and the beveled nut *c* which screws on the threaded portion of the front of the chuck.

A form of **chuck for holding thin bushings** when grinding internally is shown in Fig. 31. It consists of a holder *a*, which is mounted on the work spindle of the grinder; a removable threaded cap *b*, which fits the front end of the holder; a threaded collar *c*, which fits the inside of the holder; and the plates *d*, having holes slightly larger than the hole to be ground.

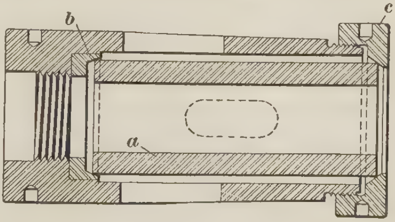


Fig. 30

This chuck holds the bushing by clamping it endwise. A centering plug *e* is used when setting up the work; it serves to hold the work in position while being clamped, and is withdrawn when the bushing is firmly held. The bushing to be ground is shown at *f*. Bushings of different diameters may be ground in this chuck when additional plates *d*, having holes of different sizes, are supplied; and bushings of any length within the capacity of the holder may be held by adjusting the collar *c*.

82. For special work that is to be done in large quantities, *special chucks* may be made to advantage. Many forms of work made of iron and soft steel are held, when grinding, by *magnetic chucks*, which not only hold the work securely, but are less liable to bend or spring the work.

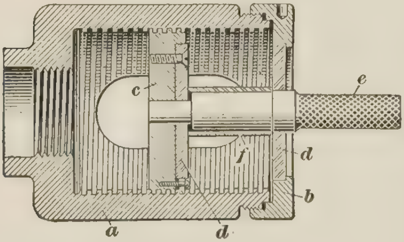


FIG. 31

83. Face-Plate Work. For the internal grinding of work whose form requires it to be held on a face plate, the work is held by clamping devices similar to those used in lathe work; or by the magnetic chuck. Great care should be taken not to bend the work by clamping.

84. Cylinder-Grinding Machines.—Special machines have been designed for use where accuracy of the work and rapid removal of stock are of prime importance. Such objects as automobile cylinders present difficulties to the ordinary grinding machine, as they cannot be rotated during the grinding operation. Boring and reaming of automobile cylinders does not produce satisfactory work, since hard spots in the casting will cause the thin wall to spring away from the tools. Neither hard nor soft spots in the metal, nor port holes left in the casting, is of consequence when the cylinders are finished by the grinding machine, since very little pressure is required to make the grinding wheel cut properly. A cylinder-grinding machine for this kind of work is illustrated in Fig. 32. By allowing large vertical, crosswise, and longitudinal adjustments, the manufacturers of these machines have made it possible to successfully grind a wide range of special work.

The main feature of the cylinder-grinding machine is the grinding-wheel spindle, which is carried in an eccentric sleeve or head *a*. This head is made up of two eccentrics, both of which rotate about a horizontal axis, thus permitting the grinding-wheel spindle to rotate upon the circumference of any sized circle within the capacity of the machine. For the success of such a machine, the extension sleeve, which supports the grinding-wheel spindle, must be very heavy and rigid. The grinding wheel *b* is mounted on the end of a spindle, which is covered by the sleeve *c*; and the table *d* is adjustable sidewise and can be moved back and forth automatically. The knee *e* is adjustable and is raised or lowered by means of the crank *f*.

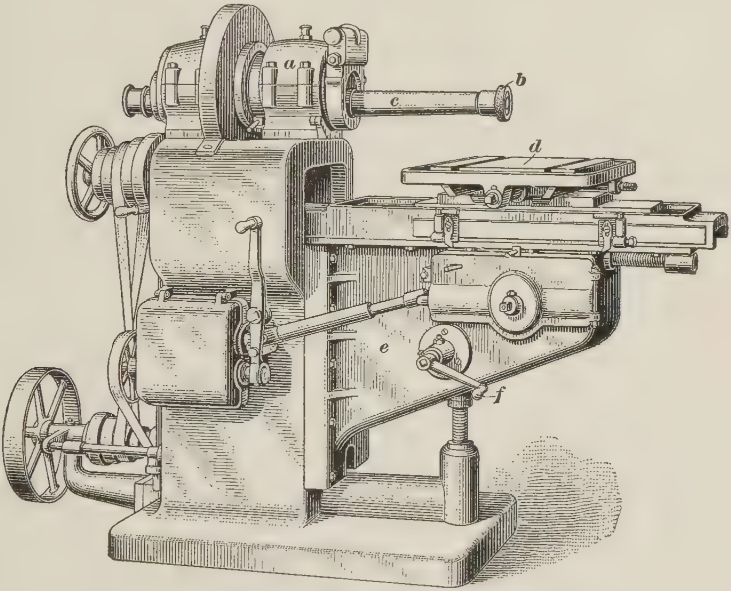


FIG. 32

SURFACE GRINDING

85. Kinds of Surface-Grinding Machines.—The grinding of plain surfaces was formerly done on an ordinary planer, which was temporarily converted into a surface-grinding machine by mounting an ordinary grinding wheel on the cross rail and providing an overhead drum for driving it. With the planer in good condition, fairly flat work could be ground; but where a very accurate flat surface was required, this method was unsatisfactory.

The majority of the surface-grinding machines now on the market are of the vertical spindle type, and use a cup or a cylinder grinding wheel. Some simple surface-grinding operations are satisfactorily performed on tool and cutter grinders; but the capacity of a machine of this kind is naturally limited and it does not adapt itself to modern manufacturing, where large surfaces must be ground in a reasonable time.

86. Several surface-grinding machines now in use have vertical grinding-wheel spindles. A successful machine of this type must be very massive, be supplied with sufficient driving power to take heavy cuts, and be designed to rapidly produce true, flat surfaces on a large variety of shapes. Some machines have a rotary as well as a reciprocating motion of the table, while others have only a reciprocating motion.

87. Vertical Surface Grinder.—In Fig. 33 is illustrated a type of vertical surface grinder, the table of which revolves, and at the same time may be fed across the wheel. This is generally known as the *rotary type*, to distinguish it from machines that have only a reciprocating motion of the table. It is equipped with a power raising and lowering device for the wheel spindle, thus making it possible to quickly lift the wheel from the work and as quickly return it. A stop is set so that on the return motion the wheel will not be jammed into the work. The wheel, wheel head, and pulley are all attached to a bracket which can be moved up and down, thus increasing or lessening the distance between the table and the grinding wheel.

The grinding wheel runs at one speed, but there are several speeds for the work. These machines are equipped with a water tank and pump, and the water is introduced inside the grinding wheel and is thrown between the wheel and the work by the revolving of the grinding wheel. The pilot wheel *a* serves to slide the table out; the lever *b* controls the speed of the table, while *c* is a clutch to engage or disengage the crosswise feed of the table; *d* is the handle by which the raising or lowering of the table by power is controlled; *e* is the switch for the magnetic

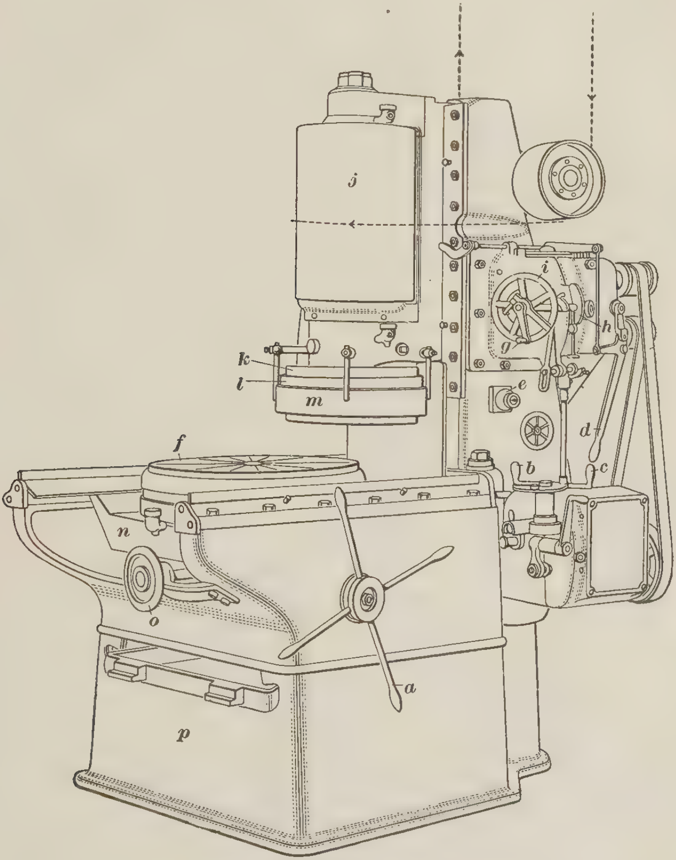


Fig. 33

chuck *f*, which will be described later; *g* is the crank by means of which the hand wheel is operated, and which, in turn, raises or lowers the grinding wheel; *h* is the pawl for the power feed, which raises and lowers the grinding wheel; and *i* is the ratchet wheel which operates in connection with *h*; *j* is a pulley fitted to the wheel spindle and is made long so that it may be moved up and down, permitting different thicknesses of work to be ground; *k* is a face plate to which the grinding-wheel retaining ring *l* is fastened; *m* is the guard around the grinding wheel to protect the operator in case of accident and also to shield him from water during the grinding; *n* is the sliding table to which the magnetic chuck *f* is fastened. A small hand wheel *o* makes it possible to rotate the table slowly when setting up the work. The water tank *p* is conveniently placed beneath the magnetic chuck.

88. Selection of Wheels.—The wheels for surface grinding should always be softer than those used for grinding revolving solids, in order to reduce the pressure of the cutting operation and the consequent generation of heat. In surface grinding only one side of the work is operated upon, and if the work is not flooded with water it will rise up in the center, as the heating and expanding of the center while the outside is cool causes the center to rise, and makes the finished part when cooled, slightly hollow.

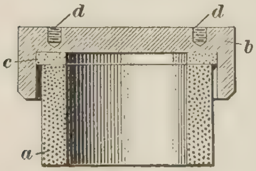


FIG. 34

The grinding wheels used are of the types known as cylinder and cup wheels, and the grinding is done on the flat surface of the grinding wheel. The wheels *a*, Fig. 34, for surface grinding machines are usually held in rings *b* by cement *c*, making it possible to change wheels in a very short time. The ring is fastened to a plate on the end of the spindle by screws which fit in the tapped holes *d*.

Surface-grinding machines are operated at a speed of between 4,000 and 4,500 surface feet per minute for the grinding wheel, and coarse, soft wheels have been found to give the best satisfaction.

89. Truing Wheels.—Grinding wheels on vertical spindle machines are trued by means of a diamond, which is placed in some kind of a holder and which in turn is held on the magnetic chuck during the truing operation. Since a straight grinding surface is required on the wheel, the truing is very simple.

90. Holding the Work.—The work may be held to the table by the same holding devices and in the same manner as is done in planer, shaper, and milling-machine work. For most kinds of work, a magnetic chuck is used successfully.

91. Magnetic Chuck.—In Fig. 35 is shown a circular form of magnetic chuck for rotating work. The electric current, which is direct, enters at *a*, passes through the magnet coils in the chuck, and leaves at *b*. Some kind of non-magnetic material *c* is used to separate the positive *N*, and negative, *S*, poles through which the magnetic lines of force set up by the current pass. The iron or steel to be ground is so placed on the chuck face that it will cover both the positive and negative poles. The work will then be rigidly held to the face of the chuck. The rectangular magnetic chucks, used for reciprocating work, embody the same principle as the rotary chuck, and both the rotary and rectangular chucks are made in various forms to suit the requirements of the work in hand. Hardened steel, when in contact with the magnetic chuck, is permanently magnetized. In this case, the work is removed by reversing the direction of the electric current through the chuck, for which

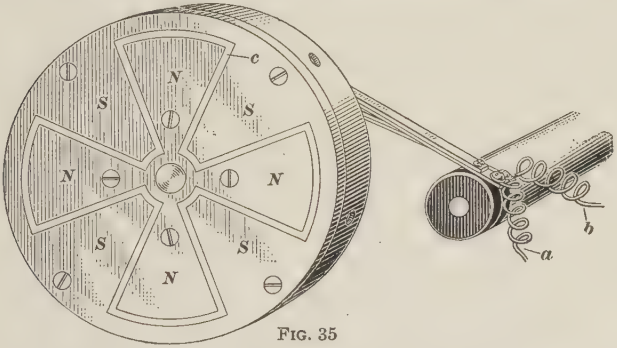


FIG. 35

purpose a reversing switch is provided. The magnetic chuck is used on the plain and universal grinding machines, as well as on surface grinders.

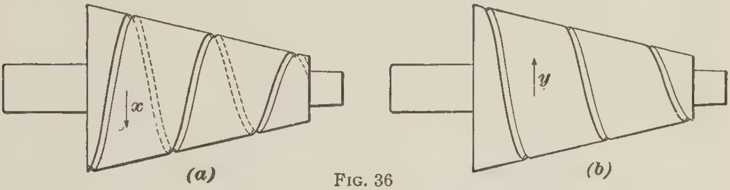
LAPPING

92. Lapping is an abrading process in which the abrading material, as emery, is embedded in some soft metal, as cast iron, brass, or lead. It is an extension of the grinding process and is aptly called the refinement of grinding. In this process, the results depend largely on the skill of the operator, and bear about the same relation to the finishing of ground work that scraping bears to the final finishing of planed surfaces. The lapping process may be used for finishing the surfaces of unhardened metal where great accuracy is required; it is more frequently employed, however, for the final finishing of hardened work.

93. The tools used for lapping are quite simple. For lapping holes the simplest lap is made of lead that is cast around an iron or steel arbor, which arbor may be made of square material, or it may be round and have a groove running lengthwise, in order that the lead will turn with the arbor. A more elaborate form of lap that is intended for cylindrical holes is made of cast iron in the form of a split shell that is placed on a tapering arbor and caused to turn with it by means of a dowel-pin. By driving the shell farther up the arbor, it is slightly expanded. Brass is a very good material of which to construct a lap; it is, however, rather expensive. Machinery steel is often used, but it cannot be said to make as good a lap as cast iron or lead on account of the difficulty of embedding the grinding material in it. The operation of applying a mixture of abrasive and oil to the lap is known as **charging.**

94. Internal Lapping.—In use, a lap is charged with abrasive and oil and is then rapidly passed back and forth across the work. If the lap is intended for a cylindrical hole, it must obviously be slightly smaller than the hole in order that it may enter when charged with abrasive; but if a true hole is desired, the lap must be as large as can be worked in the hole. For finishing laps, on fine work, no allowance is made for the cutting material when making the lap. When a lap ceases to cut, it must be expanded or a new one made. When made of lead, the lap can often be expanded by driving the arbor home a little, holding the lap in one hand. The lead, being soft, will stretch quite easily. After a lead lap has been expanded two or three times in this manner, its surface will be uneven; a new lap must then be made. The work or the lap must rotate at a fairly high speed during the lapping process. While the lapping can be done in a grinding machine, it is usually more convenient to use a hand lathe.

95. Grade of Abrasive.—The grade of abrasive to be used depends on the amount of stock that is to be removed and the degree of finish that is desired. Thus, for the finest finish, like that given to cylindrical standard gauges, the very finest abrasive flour must be used; if the lapping process is used to rough down a piece of work because no grinding machine is available, a coarse grade of abrasive may be employed. In order that the lap may work well, it must be supplied with plenty of oil.



(a) Fig. 36 (b)

96. Lapping a Conical Hole.—As the lap cannot be drawn back and forth across the surface, a conical hole is rather difficult to lap smooth. The lap is liable to cut concentric ridges into the work; furthermore, the grinding material will probably creep toward the larger end of the lap, by reason of the action of the centrifugal force due to the rapid rotation of the lap. This will cause the lap to grind the hole to a different taper than that given to the lap; but this tendency can be counteracted somewhat by cutting into the lap a spiral groove having a direction of rotation opposite to that of the lap. Thus, if the taper lap shown in Fig. 36 (*a*) turns in the direction of the arrow *x*, the groove should be left-handed; but if it turns as shown by the arrow *y* in Fig. 36 (*b*), the groove should be right-handed. Several laps must be used to lap the hole smooth and especial attention must be paid to the prevention of glazing. In lapping conical holes, much finer abrasive should be used than for cylindrical lapping.

97. External Lapping.—An external lap is usually made in the form of a ring that is lined with lead, brass, or cast iron. The length of the lap should be not less than 1 diameter for a cylinder, and can profitably be more. The ring may be split and a screw provided for closing in the lap when it has become so worn that it will not cut. When much external lapping is to be done, the ring may be furnished with a handle about 15 inches long for the sake of convenience in using it.

98. Lapping Odd Shapes.—Odd shapes are sometimes lapped to bring them to the required degree of truth and finish. Odd-shaped work is made as nearly perfect as possible by machining; a lap is then made by casting lead on the part to be finished. Laps of this kind cannot be moved back and forth to prevent them from cutting rings in the work. For this reason the same precautions should be taken that were mentioned in connection with laps for taper work.

99. Lapping Holes of Milling Cutters.—While the hole of a solid milling cutter can best be finished by grinding it in a regular grinding machine, there are many places where, on account of the absence of such a machine, grinding is impossible. Lapping may then be used. A lap that is small enough to enter the hole is placed between the centers of a hand lathe and, after coating the lap with oil and abrasive, the cutter is placed on it. The cutter should not be held with the bare hand on account of the danger of an accident; a strip of pine board may be employed to advantage in holding the cutter. While the lap is rotating, the cutter should be moved back and forth from one end of the lap to the other until the lap ceases to cut. A new lap is then made or the old one expanded, and the lapping continued until the hole is of the correct size.

100. Lapping Valve Seats of Piston Valves.—In some makes of steam engines the valve seats for the piston valves used for the distribution of the steam must be truly cylindrical and very smooth in order that the leakage of steam and the wear may be reduced to the lowest limit. These seats are sometimes finished by first grinding or reaming them when they are in place in the steam chest, and then lapping them in order to obtain a very fine and smooth surface. The lap may be made of any suitable material; after being charged with flour abrasive it is pushed back and forth through the valve seats, being rotated alternately to the right and left, until it ceases to cut. A slightly larger lap is then introduced, and the operation of lapping is repeated until the seats are truly cylindrical and smooth. The lap itself must be as nearly cylindrical as it can be made. The number of laps that will be required for each pair of valve seats depends on the condition and alinement of the two seats.

101. Lapping Plane Surfaces.—The lap may be made of any suitable material, though cast iron is thought to be the most satisfactory. The face of the lap is planed as true as possible and covered with oil and abrasive, after which the work is rubbed over it, changing the work around frequently and rubbing it in all directions. Great care is required to prevent crowning the work—that is, lapping the edges away faster than the center. The lap must be planed off frequently, as it wears out of true quite rapidly.

102. Work that is easily tipped by being moved about should be placed in a holder of some kind. Thus, suppose that the rectangular bar shown in Fig. 37 (*a*) is to be lapped on the ends so that they are at right angles to the surfaces *a* and *b*, and, consequently, parallel. A block may then be made with a **V** groove planed in one surface at right angles to the bottom surface, as shown in Fig. 37 (*b*). The work is placed into this groove, and, if small, may be held there by having a few rubber bands placed over it. The holder and the work are then rubbed over the lap. The holder insures the lapping of the ends of the work at the proper angle, and at the same time prevents the work from being tipped.

103. Lapping Circular Arcs.—An arc of a circle must sometimes be lapped to an exact radius. This can be done by a cylindrical lap having a corresponding diameter. The lap may be held between the centers of a lathe, where it is driven by a dog. An angle plate may then be clamped to the slide rest, and the work may either be held by hand or be clamped against the angle plate. While the work is pressed against the revolving lap, the slide rest is moved rapidly back and forth. This action of the lap may be likened to that of an abrasive wheel grinding a concave surface into the end of a piece that is held stationary on the rest of a grinding machine.

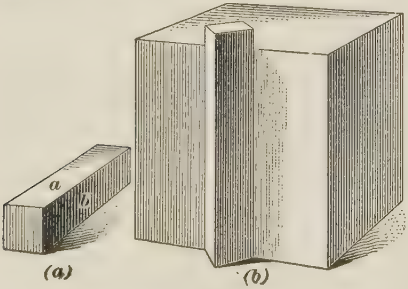


FIG. 37

104. Lapping Diamond Tools.—While the use of diamonds for taking light finishing cuts on metals, both in turning and boring, is not general, diamond tools are still used for finishing duplicate work in many shops. The diamond is employed chiefly because its hardness prevents a rapid wear; then, as the expense of sharpening tools is thus greatly reduced, it will be found that on many classes of light work the diamond tool, in spite of its great first cost, will prove much more economical than steel tools. Diamond tools are not adapted for heavy cuts, being too brittle to stand much pressure; they answer admirably, however, for very light finishing cuts, and as they hold their edge well and permit a much greater cutting speed to be used than will a steel tool, they tend to increase the output of the machine.

105. For this work the **black diamond** and the **bort** are the kinds usually employed, though sometimes white diamonds are used. The stone is set into a hole drilled in an iron or steel holder, and is lightly held by peening the metal toward the stone. The holder, with the diamond on top, is then sometimes put into a fire and the stone is securely brazed in, leaving but a small part projecting from the holder. In other cases the diamond is fastened without brazing, the metal being carefully peened about the stone. After the surplus metal has been filed away, a proper cutting edge is ground on the diamond. For this purpose a cast-iron or machinery steel wheel about $\frac{3}{16}$ inch wide and 6 inches diameter, running about 1,000 revolutions per minute, is used. The periphery of this wheel is charged with diamond dust, which is either rolled in with a small roller or hammered in with a small hammer. The grinding, or lapping, as many call it, is then done by using the wheel in the same manner as an abrasive wheel is used, the diamond being lightly held against the wheel. Owing to the hardness of the diamond, the process of lapping it to the required shape is naturally a slow one.

TOOLMAKING

(PART 1)

GENERAL TOOLROOM WORK

MATERIALS AND EQUIPMENT

MATERIALS

1. The materials most commonly used by the toolmaker are *gray cast iron, wrought iron, machinery steel, cold-rolled machinery steel, high-carbon tool steel, Stub's steel, air-hardening steel, high-speed steel,* and *semi-high-speed steel.*

2. In selecting materials, the points to be considered are hardness, toughness, ductility, malleability, compressive strength, shock-resisting qualities, adaptability to form irregular shapes and bearing surfaces, and cost.

A metal is *tough* when it is capable of greatly resisting forces that tend to pull it apart; it is *ductile* when it may be drawn out longer and thinner; and it is *malleable* when it may be hammered into shape without breaking or cracking. A metal that greatly resists compression into smaller space is said to have a *high compressive strength;* similarly, a metal that is rather easily pressed together has a *low compressive strength.* A metal that is capable of resisting shocks or suddenly applied loads is said to have a *high shock resistance,* and a metal that fails under shock has a *low shock resistance.*

3. Gray cast iron, or *gray iron,* is iron that has been melted and cast into molds. Gray iron is brittle, breaks easily,

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stretches little, and is low in cost. It is neither ductile nor malleable, has a low shock resistance, a very high compressive strength, and a good bearing surface. It cannot be forged. Owing to its method of manufacture, it is very liable to contain hidden defects, and, because of unequal cooling in the mold, internal stresses are always present. When used where accurate work is required, these stresses must be relieved, as explained later. Cast iron is used where a high compressive strength, irregularly shaped parts, a good wearing surface, or low cost is required.

4. **Wrought iron** is a very malleable iron which, owing to the presence of slag, is fibrous in structure and has a poor bearing surface. It is forged and machined, but not cast, into desired shapes; is tough and ductile; and has a medium compressive strength, and a high shock resistance. Wrought iron is low in cost; cannot be hardened, but may be case-hardened and welded. It is used but little by the toolmaker, being superseded to a large extent by machinery steel.

5. **Machinery steel,** also called *mild steel* or *soft steel,* is somewhat similar in properties to wrought iron, but contains no slag, and, owing to the absence of the slag, has a better bearing surface than wrought iron. It is forged and machined into desired shapes, is tough, ductile, and malleable, and has a high compressive strength and shock resistance. Machinery steel is low in cost; cannot be hardened, but may be case-hardened. Wrought iron and machinery steel are used for those parts of tools or devices that require a tough material capable of resisting shock, that do no cutting, and that need not be hardened to resist wear.

6. **Cold-rolled machinery steel** is machinery steel that, when cold, has been passed through highly finished rolls under great pressure. This steel possesses the characteristics of ordinary machinery steel and, in addition, is very close to size.

7. **High-carbon tool steel** contains from .5 to 1.5 per cent. of carbon and has, especially when hardened, a very good wearing surface. It is forged and machined into desired shapes

and has a very high tensile and compressive strength. It is tough and ductile, though more brittle than machinery steel, is malleable, and offers a medium resistance to shock. Tool steel is higher in cost and more difficult to work than gray iron, wrought iron, or machinery steel, and is therefore employed only when special reasons require its use.

Tool steel may be readily hardened, and is used wherever hardened surfaces are required, as in tools for cutting, pressing, and working metals into shape, for hardened centers, mandrels, bearings, bushings, etc. The outer layer of a bar of steel, as it comes from the mill, is decarbonized; that is, in the process of making the carbon has been burned out, and consequently that portion of the bar is about the same as machinery steel. For this reason an allowance for the removal of the outer layer of metal should be made, when selecting the size of steel to use for a job, and the bar should be carefully centered so that the same thickness of stock will be removed from all parts.

8. Stub's steel, or *drill rod,* is a high grade of round carbon tool steel that has been rolled cold and very closely to size. It comes in sizes from No. 80 Stub's steel-wire gauge, or .013 inch, to $\frac{3}{4}$ inch diameter.

9. Air-hardening, or **self-hardening, steel** is an alloy steel containing tungsten or molybdenum and manganese in addition to the carbon, which will harden when heated to a red heat and allowed to cool slowly in air. Considerably higher cutting speeds may be used with air-hardening than with ordinary carbon tool steels. Air-hardening steel is used only for roughing tools, as a fine finishing cut cannot readily be obtained with tools made of this steel; it will cut harder stock and is more expensive than the carbon tool steel. It may be forged and ground to shape, but cannot be annealed or machined. Air-hardening steel is used chiefly for blades of inserted-blade cutters.

10. High-speed steel is an alloy steel containing tungsten or molybdenum and chromium in addition to carbon and having the valuable property of *red hardness;* that is, the steel retains its hardness, after receiving proper heat treatment, even though it becomes red hot. High-speed steel will take larger cuts at very much higher speeds than air-hardening steel, will cut harder materials, and may be readily annealed and machined. It is more expensive than air-hardening steel and is used only for cutting tools.

11. Semi-high-speed steel is an alloy steel. It does not possess the property of red hardness, but is much tougher than the carbon tool steels and holds a keen cutting edge longer. It is annealed and hardened in the same way as carbon tool steel, and is used for thread cutting and other tools. A tool made of semi-high-speed steel may be run at higher cutting speeds, will cut harder materials, and will last longer than one made of carbon tool steel.

12. Cutting and Straightening Tool Steel.—A saw or cutter should be used to sever a piece of tool steel from the bar. It is bad practice to nick the bar around its periphery with a chisel and then break the piece off with a blow, as it will disarrange the particles of steel and, when hardened, an unsatisfactory tool is very apt to result. If a chisel must be used to cut off the stock, the steel should first be heated to a red heat and cut off while hot. If this is done, the steel will not be injured.

Should a bar of tool steel be bent, it should be heated to a red heat and straightened when hot. If straightened when cold, the finished work is very likely to spring when hardened.

EQUIPMENT

13. Both the machinist and toolmaker, in general, use the same kind of machines, but those used by the toolmaker are smaller than those used by the machinist. A large lathe would not be suitable for turning and boring small work because the spindle speed would be too slow and the variation in depth of cut cannot be felt on the handles. Should an ordinary engine lathe be speeded up to give the required spindle speed for small work, it would not only be speeded too fast for larger work but would jump and vibrate to such an extent that it would be impossible to do accurate work on it.

14. Driving of Bench Lathe.—The bench lathe, Fig. 1, has been developed to meet the demand for a lathe to finish small work accurately. As its name implies, it is a small lathe supported on a bench, and its countershaft is located so as to be not more than 3 feet from the lathe spindle. A soft canvas or leather belt is used to connect the spindle and countershaft cones. The ends of the belt are butted and, in the case of the canvas belts, are laced with strong linen threads. The leather belts are shaved to a uniform thickness and laced with tough, thin strips of eelskin or similar material. A joint made in this way will be found more satisfactory than a cemented joint, as the latter is apt, at high speeds, to pound constantly on the lathe spindle.

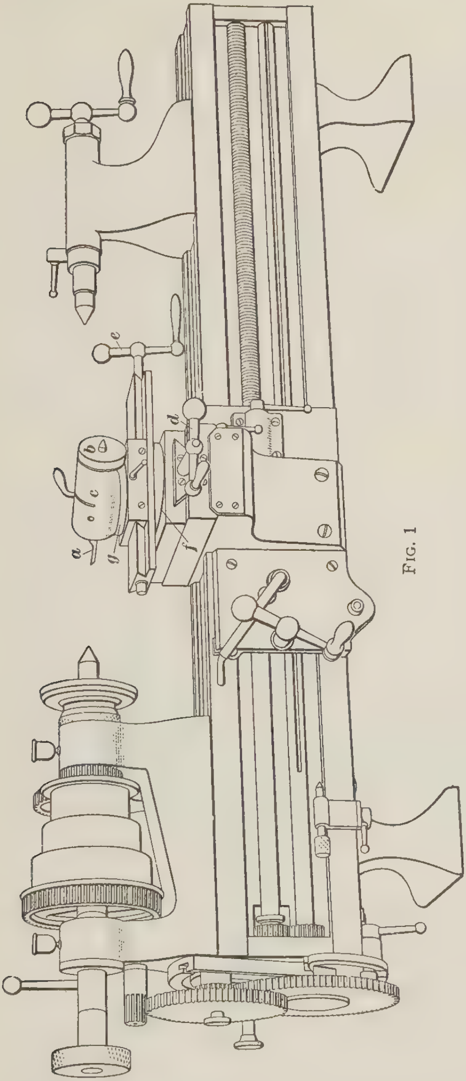


Fig. 1

15. Bench Lathe Chucks.—The chucks used on the bench lathe are of the spring-collet type, shown in Fig. 2; they vary in diameter to suit the work. They fit in the front end of the spindle, as shown in Fig. 3, the threaded portion fitting the threaded end *a* of the extension rod, or draw-in spindle, *b*. This extension rod has its opposite end *c* fitted to the hand wheel *d*, which is securely attached to it. Turning this hand wheel to the right draws the collet *f* back and closes it on the work. Turning the hand wheel to the left allows the spring in the collet to pull it forward and loosen the hold on the work. These collets are intended to hold smooth, round stock, such as drill rod, cold-rolled steel, brass rod, and finished work, and should not be used to hold rough stock or stock that is not round.

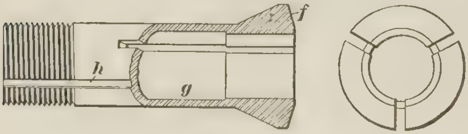


FIG. 2

As the collets run almost perfectly true, very little turning to true up the stock is required, and by the use of them small concentric work that is to be hardened and ground may be readily machined. Small punches, gauges, or similar work, when held in one of these collets, may be turned to the form shown in Fig. 4, the parts *a*, *b*, and *c* being to size and concentric.

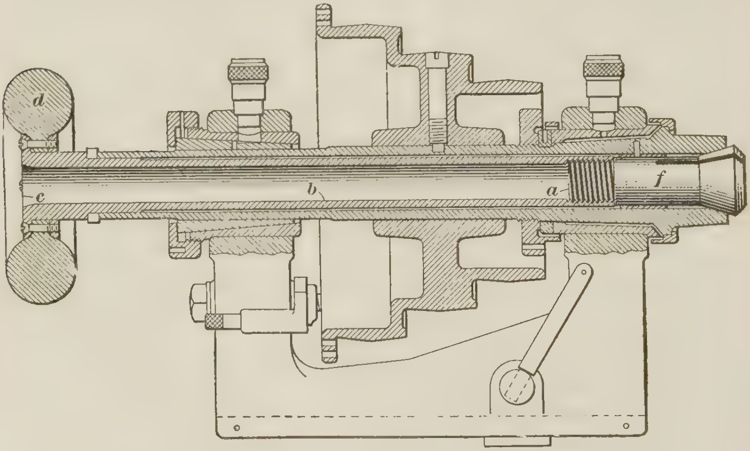


FIG. 3

When desired a little stock may be left on these parts to be subsequently removed by grinding.

16. **Turning on Bench Lathe.**—In the form of lathe shown in Fig. 1, the tool *a* is held in a cylindrical tool holder *b* that fits in the head *c* when turning, boring, facing, or chasing. The holder may be rotated to any position in the head *c* and clamped in position. The tools used are made of round stock and may be set to any desired position in the holder. The slide rest may be swiveled to any angle with the spindle. The tool may, therefore, be set with ease. The crank-handles *d* and *e* are graduated so that movements of $\frac{1}{1000}$ inch may be easily read, and the slides *f* and *g* are supplied with degree graduations by the use of which the slide may be set to turn any desired angle.

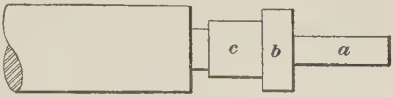


Fig. 4

17. Assuming that the work shown in Fig. 4, or similar work, has been turned nearly to size on the rod and hardened, it may now be held by the rod, ground to size by the use of the grinding attachment supplied with the machine, and cut off with a lathe tool or grinding wheel, depending on the hardness of the part to be cut. A closer concentricity of the parts of the work can be obtained if the entire outer surface is finished at one setting than would be possible if it was finished on centers, owing to the fact that the centers wear when turning, that the spindle or live center may fail to run dead true, and that a small piece of steel or dirt may enter the center and cause the work to run out of true.

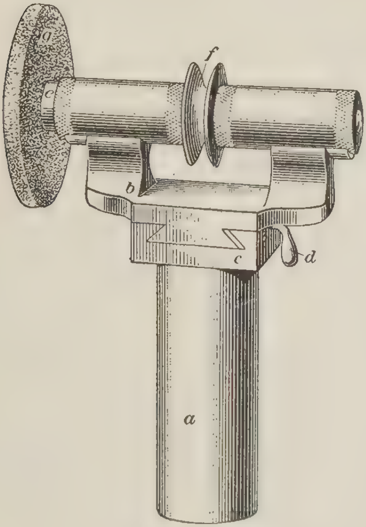


Fig. 5

18. Grinding Attachments for Bench Lathe.—By the use of the grinding attachments shown in Figs. 5 and 6, the bench lathe is converted into a small bench grinding machine. The attachment shown in Fig. 5 is used for external grinding and the one in Fig. 6 is generally used for internal grinding, although it may also be used for external work. Small work of all kinds may then be ground and lapped easily and accurately. Both attachments are held by their shanks *a* in the head *c*, Fig. 1, and the bodies *b* of both attachments have a vertical movement in the dovetailed guides *c*, and are clamped in position by the screws *d*. The grooved pulleys *f* on the grinding-wheel spindles *e* are belted to a grooved pulley on the countershaft with a light, flexible belt smoothly jointed. The grinding wheels are shown at *g*.

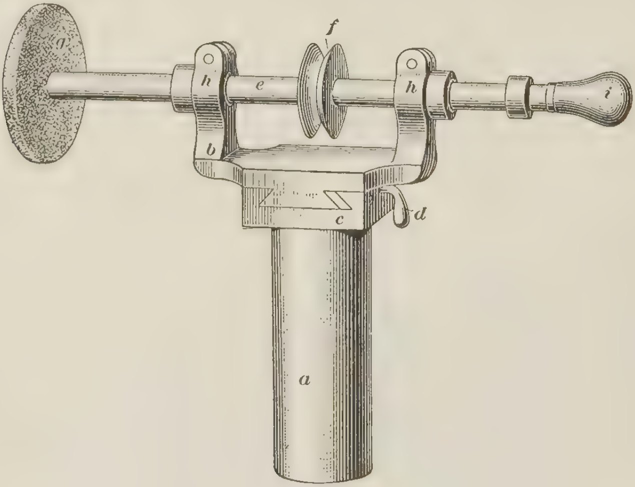


Fig. 6

The internal grinding attachment shown in Fig. 6 is operated by moving the spindle *e* that carries the pulley *f* and the grinding wheel *g* back and forth in the bearings *h* by means of the handle *i*. An attachment of this form is called a *grinding attachment with traversing spindle.*

19. An excellent belt for this attachment is hollow-woven cotton sleeving, such as is used to cover electric conductors, whose diameter is no larger than needed to drive the spindle. In Fig. 7 are shown the successive steps in splicing the belt. It is first placed in position, a lead pencil mark *a* is made on both ends, and the belt is cut so that each end extends about 2 inches from the pencil mark, as shown in (*a*). A loop, shown in (*b*), made of fine steel wire is inserted in the belt near one end as

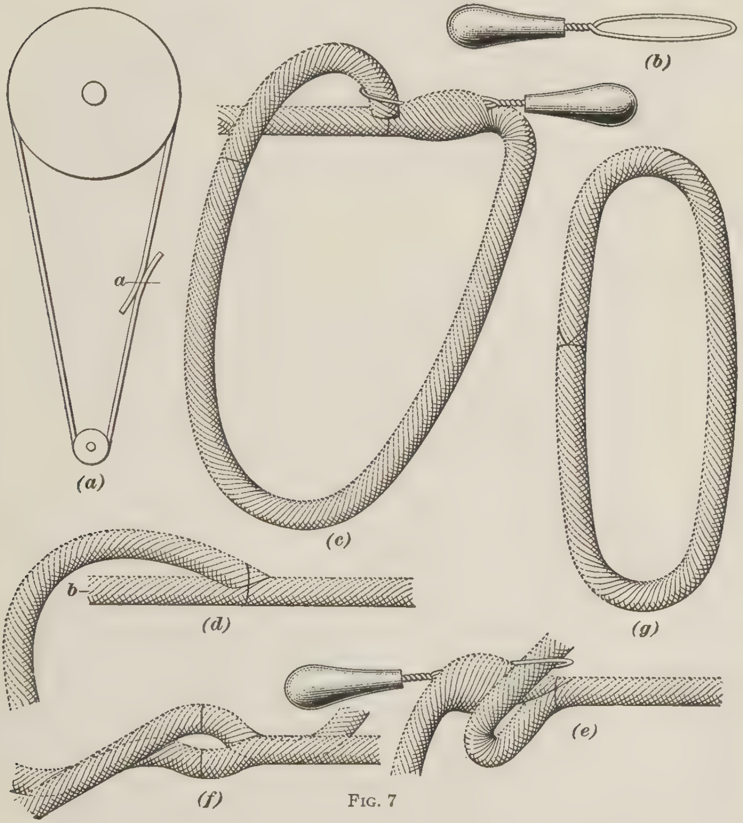


Fig. 7

shown in (*c*). The other end is placed in the loop, and pulled through it till the pencil marks coincide as shown in (*d*). The loop is then inserted in the belt near the other end, as shown in (*e*), the end *b* shown in (*d*) is placed in and pulled through this loop until the pencil marks coincide as shown in (*f*). The ends are now pulled tight and the surplus material is cut off, thus completing the joint, as shown in (g).

20. Example of Grinding on Bench Lathe.—Let it be required to grind to size the piece shown in Fig. 8, which has been previously turned and hardened, the proper grinding allowance having been left for finishing. The large straight hole, the taper hole, and all outside diameters must be concentric; that is, they must all be true about the same center line.

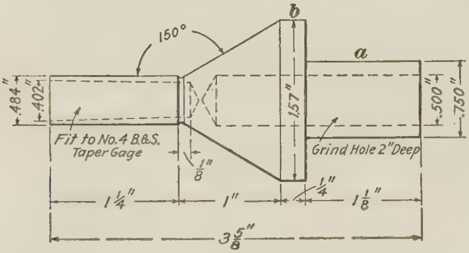


FIG. 8

The lathe may now be set up to grind the ½-inch hole. If there is a grinding allowance of .016 inch on the small end, the work may be gripped in the ½-inch spring chuck. The internal grinding attachment is then secured to the head of the slide rest, and a cloth placed over the bed and slide of the machine to catch the abrasive and prevent it from getting in the slides.

21. As the hole is to be ground 2 inches deep, it will be difficult to measure its diameter at the bottom. Great care must be taken in setting the slide rest, as errors are very likely to be introduced, owing to the fact that small dents, which escape notice, will tilt the slide rest slightly, that small particles of grit may be lodged under the slide rest, that the slide rest may not be exactly at right angles to the spindle when the zero marks are lined up, and that it is difficult to line up the zero marks accurately. By making the zero marks coincide, the slide rest is set up to grind straight, but in order to be sure that the setting is correct it is necessary to take repeated cuts across the work, take measurements for parallelism and readjust the rest until the required accuracy is obtained.

The most accurate way to set the rest is to grind a trial piece straight on the outside, using the internal grinding attachment. After adjusting the rests until the sides are parallel the trial piece is removed, the setting of the rests are not disturbed, the work is secured in the chuck, and the hole is ground to size.

22. The following method may also be used to set the slide rest to grind a straight hole. Before making final adjustment of the compound rest, a cut may be taken so that the surface of the hole will run true with its center line. The slide rest may then be adjusted until when a cut is taken the entire length of the hole, first on one side and then on the other, the volume of sparks of the last cut taken will not vary throughout the entire length of cut.

After taking a cut on the side *a*, Fig. 9, the wheel is brought to bear on the opposite side *b* of the hole until sparks are just visible. If the hole should be tapered as shown, the volume of sparks would become greater as the wheel approaches the outer end. The rest is now reset and another test is made. By repeated adjustments and trials, the rest is set to grind the hole straight.

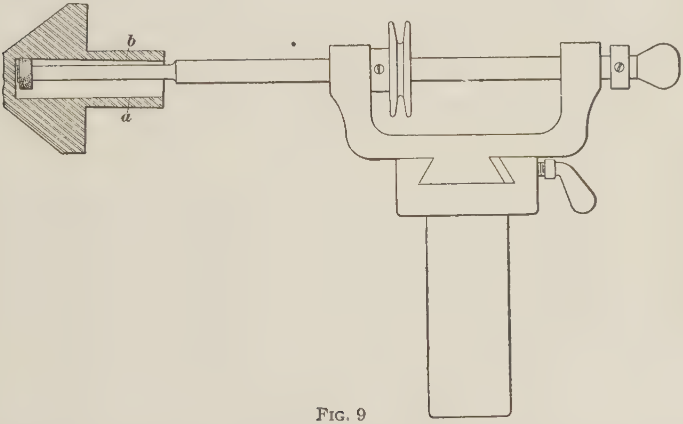


Fig. 9

23. At the same setting of the work, using the same grinding attachment, the outside diameters *a* and *b*, Fig. 8, are now ground to size. All the surfaces finished, so far, being ground at one setting, will be concentric. The work is now removed from the chuck.

A piece of steel, *c*, Fig. 10, is next gripped in the spring collet and turned very smooth and straight to a wringing fit in the hole just ground; that is, the piece is made just small enough to allow the work to be wrung over it but not large enough so that its position in the chuck will be disturbed when the work is wrung on it. The work is then put on this piece of steel. Before grinding further, the outside surface *a*, Fig. 10, should be tested by an indicator *b* to be sure that the work is running true with the ½-inch bore and the outside surfaces *a* and *b*, Fig. 8, already finished. Should the position of the turned rod *c*, Fig. 10, have been disturbed when putting on the work, it would be detected at this time.

A light cut is now taken off the surfaces *e* and *f*, Fig. 10, to remove the scale and relieve the hardening strains. The tapered hole *g* is ground to fit a No. 4 Brown & Sharpe taper plug, the part *f* is finished and the angular surface *e* is ground. The slide rest is set approximately to the desired angle, as shown by the graduations, to grind the angular surface and then shifted until the angle ground fits the shop standard taper gauge, or, if there is no gauge, until the angle ground fits the protractor *h*, which has previously been set to 150° by the use of a magnifying glass. As metal expands when heated, it will measure larger when warm than when cooled to the normal temperature, and, as grinding tends to heat the work, it should not be calipered for the finished size until cool.

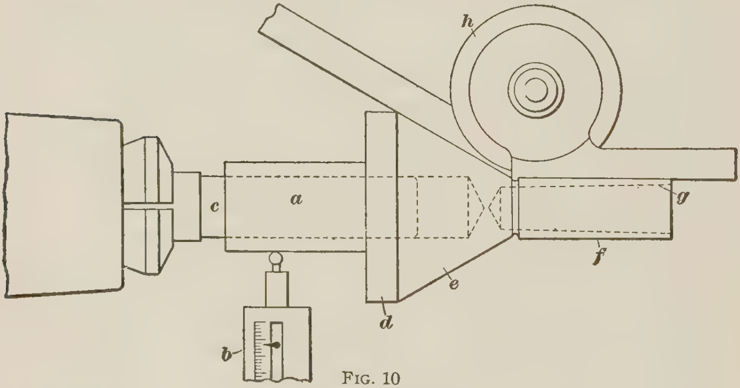


FIG. 10

24. In case the hole *g*, Fig. 10, had been so small that a grinding wheel could not have been employed to grind it, a small diamond-charged lap could have been used. When machining tapers, the center of the cutting tool is always set the same distance above the ways of the machine as the center of the work. If this is not done, a curved surface results.

25. Relieving Vibrations When Grinding.—The vibration set up in grinding long, slender work may be stopped by holding a toothpick or a light piece of wood against the end of the piece being ground. Too much pressure must not be exerted, or the end of the work will be ground to a taper.

26. Other Attachments for Bench Lathe.—Taper, spiral, threading, relieving, milling, slotting, and special attachments are made to be used in connection with the bench lathe. This machine, together with the attachments, should be used only for work that is too small to be done to advantage on the larger machines.

27. Relieving Attachment for Engine Lathe.—Hobs, taps, cutters, counterbores, and some special cutting tools, to give satisfactory service, must have their cutting edges *relieved;* that is, enough of the stock back of the cutting edge must be removed so that the cutting edge only will come in contact with the work. This stock must be removed either by hand filing or grinding, a relieving machine, or an engine lathe equipped with a relieving attachment. The teeth cannot be uniformly relieved by hand work and the correct shape of the teeth is usually destroyed when the tool is ground. By the use of the relieving attachment, however, the teeth are relieved uniformly and the correct form is retained. The teeth are then sharpened by grinding, on their faces only.

28. One form of relieving attachment is shown in Fig. 11; the same attachment is shown on the lathe in Fig. 12. To relieve a tooth with this attachment, the lathe cross-slide is moved inwardly by means of a cam acting on a roller enclosed in the case *a*, Fig. 11. The cross-slide is then returned to its original position by a spring before the succeeding tooth has come up to the relieving tool. The cam *c*, Fig. 11, is connected rigidly to the cam-shaft *b*, which is operated by a set of change gears connected to the lathe spindle, and the attachment is usually constructed to relieve work having any number of flutes or teeth from two to thirty-two. In case the work to be relieved has all its teeth in a plane perpendicular to its axis, as in gear-cutters, the carriage remains stationary during the relieving; if the teeth take the form of a helix, as in hobs and taps, the carriage travels lengthwise when relieving, exactly as it does in cutting a thread. Change gears are provided to adapt the device to the number of teeth, and plates giving the

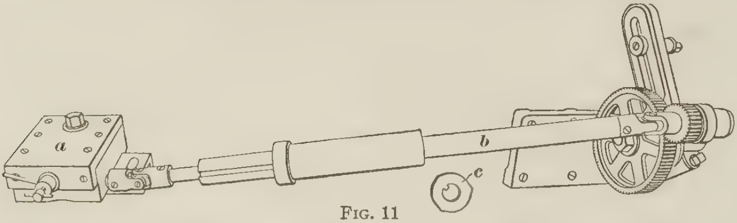


Fig. 11

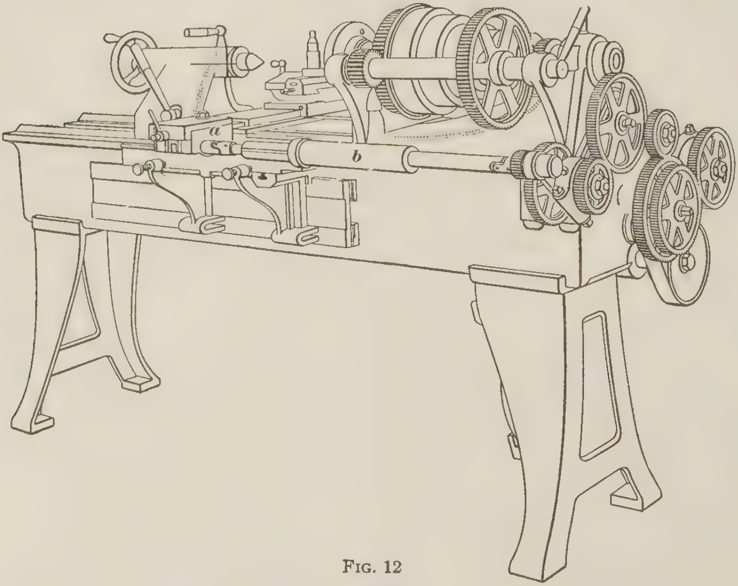
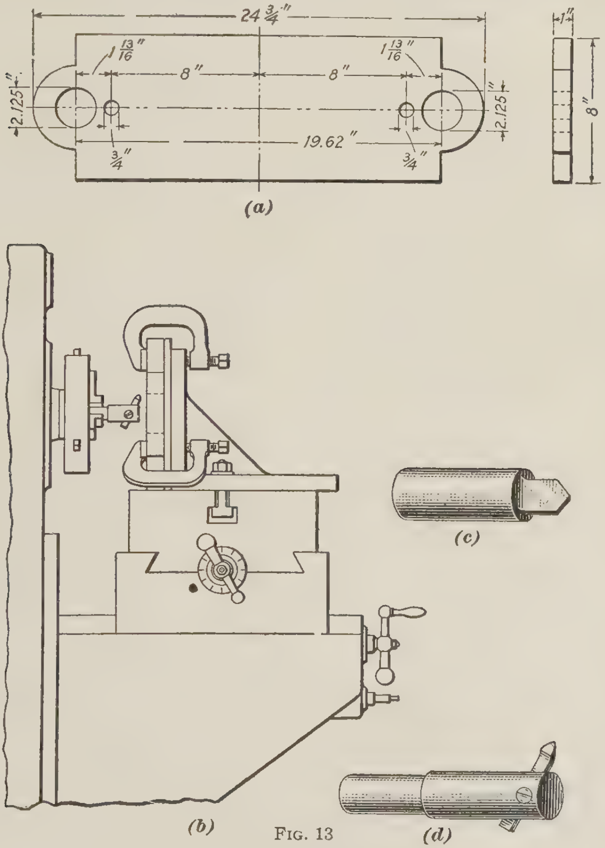


Fig. 12

correct change gears to be used in each case are attached to the machines on which relieving is done. These change gears are selected as in screw cutting.

29. Boring on Milling Machine.—The toolmaker quite frequently finds the milling machine especially well adapted



(a)

(b) Fig. 13 (c) (d)

for a boring operation. Perhaps a hole must be bored perfectly true with a part just milled. When possible the holes should be bored without disturbing the setting of the work.

In other cases the form of the work may be such that it could not be held conveniently on a lathe. The milling machine may then be used for boring. Suppose that the holes in the work shown in Fig. 13 (*a*) are to be bored. If done on a lathe, a 48-inch swing would be required. Tool rooms are seldom equipped with large machines, and, even if they were, large machines are not designed to machine small dimensions. This job may be readily bored on the milling machine. As the dimensions of the end holes are given in thousandths, the holes must not vary in diameter more than .001 inch. Similarly, the distance between them must not vary more than .01 inch. The two $\frac{3}{4}$-inch holes, being dimensioned in fractions, will be close enough to size if drilled. The work may be clamped to an angle iron on the milling machine, as shown in Fig. 13 (*b*), the edge of the work resting on the milling-machine table. In order that the cutting tool may pass through the work without injuring the angle plate, parallels are placed between them.

A spotting tool, Fig. 13 (*c*), is then gripped in the chuck on the milling-machine spindle and by adjusting the milling machine the tool is set to spot one of the end holes. When this hole has been spotted, the table is moved lengthwise $1\frac{13}{16}$ inches, the measurement being made by the graduated dial attached to the adjusting screw, and the second hole is spotted. The usual method of taking up the backlash of the screw must, of course, be followed carefully when setting work by means of the milling-machine dials. In a similar way the remaining two holes are spotted. A $2\frac{1}{16}$-inch drill is next gripped in the chuck and one of the end holes is drilled, after which the table is moved lengthwise 19.62 inches and the other end hole is drilled. A $\frac{3}{4}$-inch drill is then put in the chuck, the table is moved lengthwise $1\frac{13}{16}$ inches, and one of the inside holes is drilled, after which the table is moved 16 inches farther lengthwise, and the other inside hole is drilled. A boring tool, Fig. 13 (*d*), is now gripped in the chuck, the table is moved $1\frac{13}{16}$ inches farther lengthwise, and one of the end holes is bored to size. The table is next moved back 19.62 inches and the other end hole is bored to size. As the holes must be bored to within .001 inch of the nominal size, care must be taken in boring them. A good way to measure the holes accurately is to set a caliper square to the hole and measure the distance across the measuring points with a micrometer.

PROCEDURE AND MEASUREMENTS

PROCEDURE

30. In modern factories, producing duplicate work, when the manufacture of a new article or change in an existing one is contemplated, the work is begun in the drafting room, or engineering department. A general idea of what is wanted is given to a skilled draftsman, who makes working drawings embodying all the desired features. The drawings go to the model-making or experimental department, where a complete model is made. This model is tested and modified until approved. Completed drawings, embodying all the changes made in the model, and possibly the model also, go to the tool designer, who designs and makes drawings for the jigs, fixtures, punches and dies, templets, and all special tools needed for the rapid completion of each operation on each part of the model, and specifies on the drawings the material to be used, the finish required, the symbols to be stamped on the parts and the hardening, case-hardening or other treatment needed.

Some shops, however, do not employ tool designers. In this case the foreman of the toolroom, aided by pencil sketches, explains verbally to the toolmaker what is wanted, and the toolmaker makes the tool.

31. The work of the toolmaker comprises the making of the small special tools, such as taps, threading dies, reamers, milling cutters, and such tools as jigs, punches and dies, and gauges, used in the production of duplicate work. It being the tendency to specialize in every direction of machine-shop work, the journeyman toolmaker today does not generally build the machines himself, but, instead, produces the tools and special appliances for the construction of the machines in an economical manner.

The making of taps, threading dies, reamers, milling cutters, and similar cutting tools is, in most shops, but a relatively small part of the toolmaker's work and is limited to special forms. As many concerns make a specialty of the standard forms of such tools, they can be bought of the makers for a small fraction of what their cost would be if made singly and with the facilities usually found in tool rooms. Many tools thus bought are superior to home-made tools, because the makers have the best facilities to make them.

The production of jigs, fixtures, punches and dies, gauges, templets, and special tools used where articles are manufactured in quantities under the interchangeable system, and such special tools as tend to cheapen the cost of manufacture, form, in general, the greater part of the toolmaker's work.

32. Construction of Tools.—The toolmaker is very frequently called on to solve problems that, while not essentially different from those of the machinist, still require entirely different methods of procedure to accomplish the object sought. Thus, the problem of locating and drilling two bolt holes 3 inches apart, when the bolts have a clearance of $\frac{1}{16}$ inch or more, is solved in an entirely different manner from that of producing two holes with their axes parallel and in the same plane, and 3 inches apart, within a limit of variation not to exceed .00025 inch. In the first case, the combination of a drill press, center punch, hammer, 2-foot rule, a drill, and a machine operator will usually be sufficient; in the second case, an accurate lathe kept in the best of condition, fine measuring tools, standard test gauges, an extremely sensitive indicator, and other special appliances used by a highly skilled toolmaker, will be needed to do the work within the given limit of variation.

In the construction of a tool, the purpose of every part of it must be considered in order to prevent undue accuracy and unnecessary expense consequent thereto. It is a mistake to accurately machine, scrape, and finish parts where an accurate surface is not required. The time needed for this can be spent more profitably on those parts that accomplish a useful purpose; likewise, it is unnecessary and a direct waste of time to go to the utmost refinement of measurement in a gauge that may be satisfactory if accurate within $\frac{1}{64}$ inch—as a gauge for the blacksmith, for instance.

33. Planning the Work.—Before starting to make a tool or device, the toolmaker should study the drawing until he thoroughly understands the parts to be made, and then decide on the method to be followed. This careful study prevents mistakes and saves time. Every part should receive careful consideration as to the best way to begin, which machine can be used to best advantage, and whether special tools are needed. Several days may be required to make special tools for the job, and the making of these tools is called "rigging up for the job." The operation that was rigged for can then often be done in a few minutes. As many operations as possible should be done at one setting; for this reason, it may be best to bore a hole on the milling machine that otherwise would be bored on the lathe.

34. Devising Methods.—The work of the toolmaker consists, not merely of boring a hole or turning a piece accurately to a predetermined dimension, but also of devising and inventing methods whereby each particular part, especially if it is of intricate shape and difficult to hold in the machine, can be completed with the least possible errors in all dimensions involved.

35. The toolmaker should never be satisfied with the toolmaking methods known and here described, but must be on the lookout continually for better ones. A job requiring accurate workmanship should never be started without mentally reviewing every method known. If, with the best-known method, there is a chance for inaccuracies to creep in, a better method for the troublesome job should be devised. Hence, the devising of methods is an important part of the toolmaker's work.

If one were to depend, for his knowledge of toolmaking, entirely on the jobs actually done by himself, years would be required to obtain the knowledge that an expert workman must have. It is, however, possible to learn much more about toolmaking in a specified time by close observation of the methods used by fellow workmen and by reading and studying carefully selected descriptions of the making of tools and devices than is possible by experience alone.

MEASUREMENTS

36. The measurements to be made in tool construction may be divided in two general classes: (1) *Approximate measurements;* (2) *precise measurements.* The adoption of one or the other class of measurement depends on the accuracy required. In most cases, both classes are used when making a tool, since a tool is rarely of such shape as to require measurements of precision for each and every part of it.

37. Approximate measurements are those made with the aid of an ordinary graduated steel scale and a caliper, dividers, scribing block, surface gauge, etc., or measurements that may be classified as direct visual measurements. While an expert using the greatest care and working with a magnifying glass can set calipers by a steel scale within a limit of variation of .001 inch of the true size, there are rather few people that can do so. Generally speaking, the limit of variation—that is, the degree of accuracy attainable—may be placed at .002 inch; quite close work is required to attain this accuracy.

38. Precise measurements depend primarily on gauges of various kinds that represent commercially accurate subdivisions of the standard yard. These gauges, among which may be mentioned the standard end-measure pieces made by Pratt & Whitney and the reference disks made by Brown & Sharpe, are carefully ground and lapped to a size not varying more than .00002 inch from the true size. Gauges of this degree of accuracy are naturally quite expensive, and hence are not intended for use in the machine shop, but rather for the testing of micrometers, vernier calipers, and similar shop-measuring instruments. The precise measurements that the toolmaker is usually called on to make depend for their precision on his sense of touch, they being chiefly measurements of contact. As a matter of course, it is here assumed that the measuring instrument used —as a micrometer, for instance—is commercially correct.

39. With an accurate instrument and a finely developed sense of touch, a surprising degree of accuracy can be obtained by direct-contact measurement. Instances are numerous where toolmakers have finished work that, upon testing by more refined methods, was shown to be accurate within .00003 inch. To attain this degree of accuracy, a long training is required; however, very little work that the toolmaker is called on to do will need to be within this limit. To attain accuracy within a limit of variation of .0001 inch is possible for almost any one that possesses a sensitive touch. It may sound like a very small amount, but its magnitude will be realized very forcibly when a hardened, ground, and lapped cylindrical plug is placed between the anvils of a micrometer set to just touch the plug. Let the micrometer be screwed up .0001 inch and let the difference in the force required to push the plug through the opening be noted. The difference will prove a surprise to any one that has never felt this demonstration of the magnitude of the tenth part of one-thousandth of an inch. While granting that an expert may attain a greater accuracy, generally speaking, the limit of accuracy of ordinary contact measurements may be placed at .0001 inch.

40. Accumulation of Errors.—It must not be inferred, however, that all work can be done or is done within this limit of variation; while it is possible to attain this accuracy for *one* contact measurement, it is unreasonable to expect to get it when a number of successive contact measurements must be made in order to obtain a precise overall dimension. Naturally, the total error will probably be more than the error of each individual measurement.

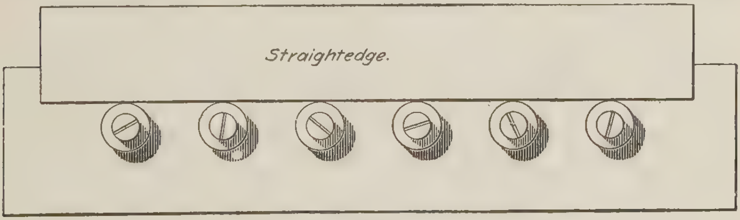


FIG. 14

A case illustrating this is shown in Fig. 14. The problem is one that frequently arises. In this case, a row of six holes is to be bored in some part of a jig; the holes are to be in a straight line and 1 inch apart. The holes must be bored with the greatest possible degree of accuracy attainable, assuming that the measuring instruments at hand are limited to a 1-inch micrometer, a sensitive indicator, and test gauges. Under the circumstances, some toolmakers would locate the centers of the holes by temporarily attaching small annular circular steel disks, called buttons, of known diameter to the work by fillister-headed screws and placing them the required distance apart by the aid of a temporary gauge filed up to a length equal to the center distance of two adjacent holes diminished by the sum of the radii of the two adjacent disks. If all disks are alike, the same temporary gauge will answer for each division. The disks are placed in line by being brought up against a true straightedge. The work is then placed on the face plate of the lathe and trued up until one disk runs true; the disk is now removed and the hole bored. This operation is repeated until all the holes have been bored. Now, while each hole may have been located originally within, say, .0001 inch, the errors of each measurement may have accumulated until the center-to-center distance between the end holes may vary an amount considerably in excess of the limit of variation of a single contact measurement.

41. In a job of the kind here shown, the errors that prevent absolute accuracy are as follows:

1. The error of the measuring instrument. With an instrument purchased of a reliable maker, this error is usually exceedingly small.
2. Error in measuring the size of the disks. This should not exceed .0001 inch.
3. Error in making the temporary gauge. This need not be more than the previous error.
4. Error in placing the disks equidistant and at the required distance. Its magnitude will be a combination of errors 2, 3, and 4. These errors may accumulate or neutralize, partly or entirely.
5. Error in chucking the disk to run true. This error need not exceed .0001 inch if a sensitive indicator is used.

6. Error in boring. Its magnitude depends on the skill of the toolmaker; it may be infinitesimal or quite appreciable.

7. Error in setting the buttons in line with the straightedge. The greatest error is to be found here.

Examining into these errors and knowing that some of them cannot be obviated entirely, it is seen that the best that can be done is to reduce each individual error to the lowest possible limit. The better the sense of touch is trained and the greater the skill used, the closer will be the final result.

42. Reduction of Accumulating Errors.—With a 2-inch micrometer at the disposal of the toolmaker, error 3 can be eliminated entirely, since the micrometer can be used directly over any two adjacent disks. Error 4 will also be reduced, since there is one measurement less to be made for the location of any two adjacent disks; that is, there are now three contact measurements instead of four. Error 2 can be diminished when the disks are exactly alike by placing three or four of them on a surface plate, pushing them all in contact with a straightedge and one another, measuring their combined sizes and finally dividing the measurement by the number of disks. Error 1 cannot readily be eliminated by any means at the command of the toolmaker. Errors 5 and 6 can be minimized by careful work. Error 7 can be eliminated by using a height gauge instead of the straightedge to line up the buttons.

43. From the preceding discussion, it is seen that a careful study of the way in which the measurements can be made is advisable in order to secure accuracy. In general, it may be stated that, to secure the greatest accuracy when successive contact measurements are necessary, the measurements should be reduced to the smallest number feasible with the measuring instruments at disposal. When successive measurements are needed for intermediate parts and the object sought is accuracy of the combined length of these intermediate parts, in addition to their own accurate location, make, first of all, the longest measurement circumstances permit, and from it obtain the subdivisions. This rule applies not only to precise measurements, but to approximate measurements as well. For illustration, assume that, in the job shown in Fig. 14, the distance between the end holes is required to be as precise as it can be made. Then, facilities permitting, the two disks locating the end holes should be adjusted first of all, and the intermediate disks from these in turn. The following may be laid down as a general rule:

Rule.— *Where several methods of measurement are feasible, the method that involves the fewest and most direct measurements should always be chosen.*

44. Considering the different methods of measurement that may be used, it will be seen upon reflection that no specific rules can be given. The toolmaker must consider the means of measurement at hand and the nature of the job; he must then use his ingenuity and be guided by his practical experience.

45. For measurements that must be made within a smaller limit of variation than is attainable by direct-contact measurements, special forms of measuring machines based on the principle of the micrometer are used. In these machines, special devices show the *degree* of contact of the measuring surfaces with the work. Such devices are to be found in a few of the leading shops where accurate work is done, being intended for measurements within a limit of variation of .00002 inch. They are used rarely for work other than making standard gauges intended for testing the ordinary measuring instruments.

LIMITATIONS OF TOOLMAKING

46. The limitations of toolmaking are twofold; they are *limitations of accuracy* and *commercial limitations*. The first depend ultimately on the skill, knowledge, and ingenuity of the individual and the mechanical resources at disposal. In many cases, a sharply defined limit is set by restriction as to cost. The second depend on the conditions of each particular case; theoretically, they may be said to have been reached when further refinement fails either to reduce the cost of production or to improve the quality. Commercial limitations are generally reached in practice when the cost of production has been reduced below that of competitors. At this period a halt is usually called to the devising of new tools or the improving of old ones until further advance is made necessary by competitors lowering the selling price or bettering the quality of the product.

EXAMPLES OF TOOLMAKING AND TOOLMAKING OPERATIONS

DOWELING HARDENED PIECES

47. When the work is hardened, the location and shape of the holes will change. In order that the work to be hardened may be doweled when properly located together after hardening, the dowel holes may be drilled larger than the required dowel size and bushed with a soft-steel bushing, into which the dowel is fitted. Suppose that the parts *a* and *b*, Fig. 15, are to be hardened and doweled together. The holes are drilled large and tapped with a tap of fine pitch. The parts are then hardened and ground, and soft-steel threaded pieces *c* and *d* are screwed tightly into the tapped holes and dressed off flush with the top and bottom of the work. The work is now properly located, clamped together, drilled, and reamed for the dowel-pins *e*, which are then fitted to the holes.

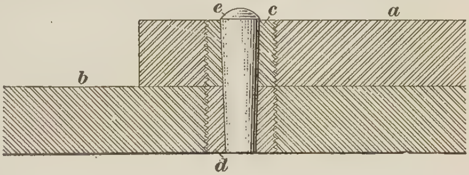


FIG. 15

MACHINING PARALLEL SURFACES

48. Making Parallel Strips.—When parallel strips that do not require great accuracy must be machined, they may be held in a machine vise; but this method cannot be depended on when the greatest accuracy is desired. A new machine may be accurate, but continued use of the vise causes it to wear and the table is likely to sag, owing to the unevenness of the foundation or the pressure of the work. Other methods of holding must therefore generally be used.

In some cases the surfaces may be turned parallel on the face plate of a lathe. If this method is used the best results are obtained if the face plate is trued while in position, by first taking a light cut across it. If a shaper, planer, milling machine, or surface grinder should be employed, the parallel faces should first be machined to within a few thousandths of an inch of the finished size, the work then removed and a piece of scrap cast iron or steel, or a plate kept for the purpose, clamped to the table of the machine, and trued up by taking off a light cut. This piece is sometimes called an auxiliary table or bed. The work is then fastened lightly to this piece and finished to size.

49. A method of holding the work is shown in Fig. 16, in which *a* is the work and *b* the auxiliary table. Holes are drilled in the auxiliary table and poppets *c* are set into them. The work is then placed against pins, not shown, and held to the surface by fingers *d*, set at an angle as illustrated and tightened by means of the poppet screws *e*.

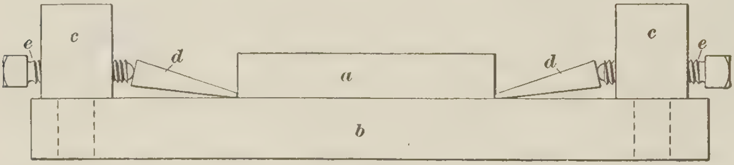


FIG. 16

If a magnetic chuck is used its surface should be trued after it has been set up on the machine.

50. Methods of Holding Thin Work.—If the work to be machined parallel is very thin, it is liable to be distorted when clamped to the table or gripped by the magnetic chuck. To prevent this, the work is first machined nearly to size and then stuck to the auxiliary table by means of wax, which is applied with a soldering iron in the same manner as solder. Stop-pins are used to take the thrust due to the cut.

A suitable wax for this purpose is composed, by weight, of 7 parts of beeswax, 2 parts of resin, and 1 part of shoemaker's wax. These parts are thoroughly mixed by being melted together. When used on the grinder, light cuts, about .0005 inch, must be taken or the friction of the wheel will warm the work sufficiently to melt the wax and release the work. When used on the shaper, cuts of .005 inch may be taken. The wax may be removed from the work by the use of a copper scraper and by wiping it with a cloth wet with gasoline.

MAKING A MANDREL

51. Turning.—A **mandrel** is a simple tool and apparently easy to make; but, various conditions must be guarded against in making it, and these conditions the toolmaker must daily overcome. For this reason, the making of a 1-inch mandrel, shown in Fig. 17, will be described fully.

A straight piece of tool steel, $1\frac{1}{8}$ inch in diameter, is selected. This diameter is chosen in order that the outer surface, which is somewhat decarbonized in the manufacture, may be removed. The piece is now cut to the desired length and carefully centered with a combination countersink and drill; after this the piece is placed between the centers of a lathe and the ends faced. The centers are then carefully cleaned, the ends *a* and *b* are turned to size, the body *c* is turned to about .015 inch over size, the flat spot *d* is milled, and the size stamped on the end *a*. The mandrel is now ready to be hardened.

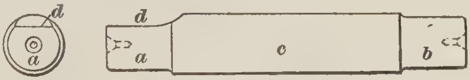


Fig. 17

52. Hardening.—In hardening, the mandrel must be uniformly heated to insure uniform expansion. This heating may be accomplished in a muffle furnace; or, if an open fire must be used, by placing the mandrel inside a piece of iron pipe to prevent direct contact with the fire. If the pipe were not used, the blast necessary in the forge would cause flame to strike the mandrel unevenly and the parts of the tool in direct contact with the flame would therefore expand most.

The mandrel should be gripped with a pair of tongs and turned and shifted in the pipe until it reaches the desired temperature. The desired temperature is about 1,300° F., or a bright, cherry-red heat. When the proper temperature is obtained the mandrel is gripped on one end with the tongs, plunged vertically in the water, and moved up and down until it is cool enough for the finger tips to remain in contact with it without being burned or until the tongs cease to vibrate. To avoid setting up internal strains, which are greater on large than on small pieces, the mandrel should not be kept in the bath until chilled throughout. These strains are caused by the contraction of the outer surfaces while the center of the work is still red hot. When the work is removed from the hardening bath while quite warm, the heat from the inside rushes to the outside of the piece, and the contraction in the final cooling is more even.

The temper is now drawn by placing the tool in oil heated to 450° F. or by polishing it and rolling it back and forth on a hot plate until a light straw color appears. The mandrel is then placed on a board or some material that will not conduct the heat away rapidly and allowed to cool.

53. Distortion of the Center.—Mandrels are invariably used between the centers of a machine. Hence, to insure the mandrel running true, it must have perfect centers. After hardening, however, the centers are rarely round. If the mandrel was ground to size without first truing its centers, after being in use a short time the high spots would wear off and consequently the mandrel would *run out;* that is, it would not run true.

54. Lapping the Centers.—The centers are generally trued up by the use of a rotating lap or a grinding wheel attached to a grinding fixture held in the tool post of the lathe, as shown in Fig. 18. A soft-steel wheel, or lap, *d*, having a shank that fits the taper hole in the grinder, is used when lapping. The mandrel is secured to the face plate of a lathe by means of a dog *f* and rawhide lacing, and is supported near its end by the steady rest *g*. The tool-post grinder *h* is fastened to the lathe tool post *i* and the slide rest *j* is set at an angle of 30° with the center line of the mandrel. The lap *d* is now charged with diamond dust or emery, preferably with diamond dust, by rolling it between two smooth, hardened blocks, on the lower one of which the abrasive mixed with oil has been placed. During the lapping, the lap is rapidly rotated and kept moistened with a thin lubricant. In this way both centers are lapped round and to the correct angle. The mandrel is then ready to be ground.

55. Grinding the Mandrel.—Mandrels are ground to a taper of about .01 inch to the foot. A 1-inch mandrel 8 inches long may be made 1.004 inches at the large end and .997 inch at the small end. A rigid wet-grinding machine equipped with dead centers is best for grinding them. If the grinding machine has one dead and one live center, the live center should be carefully tested with a test indicator and ground true if the indicator shows the slightest movement. Any inaccuracy in the live center will, of course, appear in the work ground on it. A wet grinder is preferable on this class of work, because the water not only keeps the work cool but also washes away the small

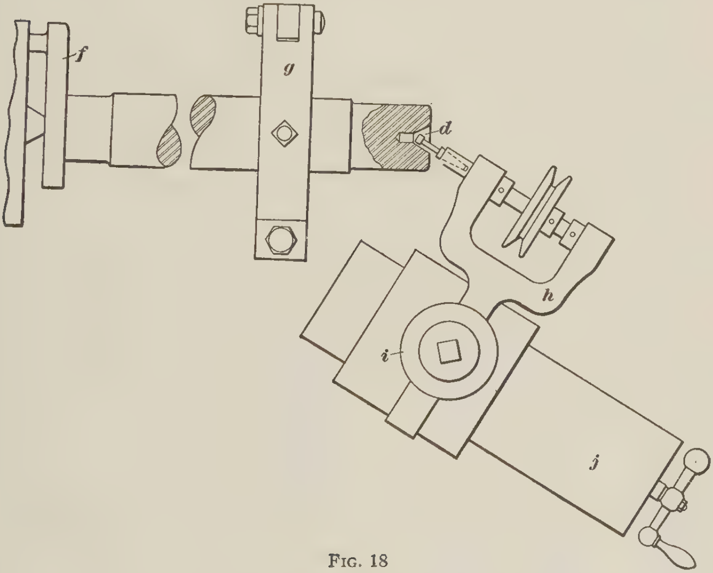


Fig. 18

chips and assists in keeping the wheel clean. The wheel is trued carefully on its face, and light cuts are taken on the mandrel to prevent crowding it against the centers and to prevent heating.

MAKING SPRING COLLETS

56. Machining and Tempering.—Let it be required to make the spring collet shown in Fig. 2. A piece of tool steel of diameter about $\frac{1}{8}$ inch larger than the largest diameter of the collet is selected. As slots are to be cut and the ends *f* are not supported, they will warp in hardening. To avoid this the piece must be made so long that when the slots are cut the ends *f* will be supported. After the hardening is done this extra length of stock is ground off. The stock should therefore be cut off about $\frac{1}{2}$ inch longer than the finished part. The piece of steel is then chucked on a lathe, and the clearance hole *g* is spotted, drilled, and reamed. A short rod is now gripped in the chuck, as shown at *a*, Fig. 19, turned so that the clearance hole just bored in the work *b* will be a wringing fit on it, and the work is wrung onto the rod, care being taken not to disturb the position of the rod in the chuck. The end *c* is then spotted, drilled, and countersunk, and the work is removed, placed between the lathe centers, and turned to the shape shown in Fig. 20 (*a*), proper allowance being made for grinding after hardening.

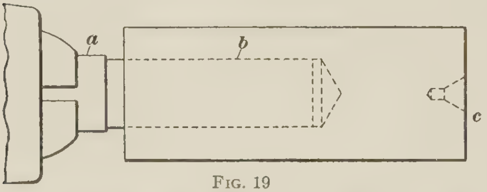
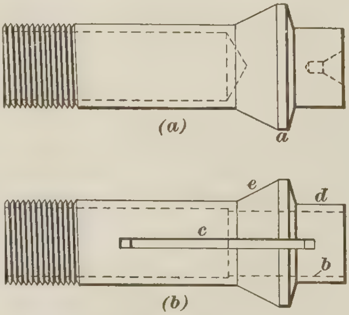


FIG. 19



(*a*)

(*b*)

FIG. 20

57. The steady rest is next set up on the lathe with the surface *a*, Fig. 20 (*a*), of the collet bearing against the jaws of the rest. The hole *b*, in (*b*), is then drilled and bored nearly to size, leaving enough metal to true up by grinding after hardening. The spline *h*, Fig. 2, and the three slots, one of which is shown at *c*, Fig. 20 (*b*), are now milled in the collet as shown, but not through the end *d*. This end *d* is left on the collet till the hardening and grinding are finished, to prevent the jaws from springing out of shape and to provide means to support the work when grinding. The collet is now hardened, being left quite hard at the grip end, while the screw end is drawn to a spring temper.

58. Grinding.—The collet is held on the grinding-machine centers and ground to size, the angular surface *e*, Fig. 20 (*b*), being ground to fit a templet or bevel protractor. The collet is now placed in the lathe head in which it is to be used, or in the head of a lathe used for the purpose of grinding collets, and drawn into place in the spindle. A small grinding wheel such as shown in Fig. 21 (*a*), or a soft-steel rotating wheel charged with abrasive, is used to grind or lap the hole to size.

59. When lapping, the wheel must rotate rapidly and be kept moist with thin oil, and must not be crowded. When a steel wheel is used, the small particles of abrasive are merely sticking in the wheel, and when it is crowded or run dry they will be torn out. When lapping holes smaller than $\frac{3}{16}$ inch, wheels charged with diamond dust, and a *harker*, shown in Fig. 21 (*b*), must be used. A harker is a very sensitive contact detector. It consists of a $\frac{3}{32}$-inch rod *a* about 10 inches long, with a fork on one end, and a wooden ear piece *c* on the other end. By placing the forked end on a stationary part of the grinder close to the work and holding the wooden end to the ear, one can tell, by the vibration, the instant the

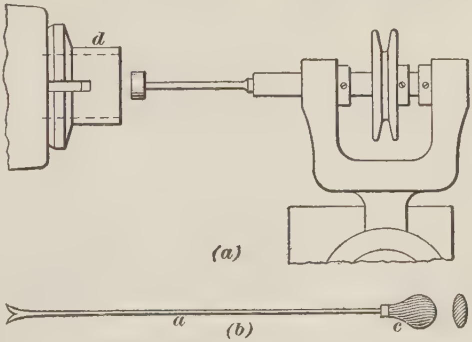


FIG. 21

wheel touches the work. Without the use of the harker, the lap will be ruined at the outset.

After the hole is ground to size, the end *d*, Fig. 20 (*b*), is ground off, and the collet is ready for use.

METHODS OF LOCATING HOLES

60. Approximate Methods.—Suppose that in a piece of work three holes are to be cut parallel, and of the same diameter, and with the same distance between the holes as in a model that is furnished. If an error of several thousandths of an inch is permissible, the *jig method* may be used. In this case, the work and model are clamped together and the model serves as a jig. The holes are made with a twist drill on a drill press. The inaccuracy of this method is due to the fact that the drill rarely fits perfectly in the guide holes, and the drill-press bed is not likely to be at right angles to the spindle unless the machine is new.

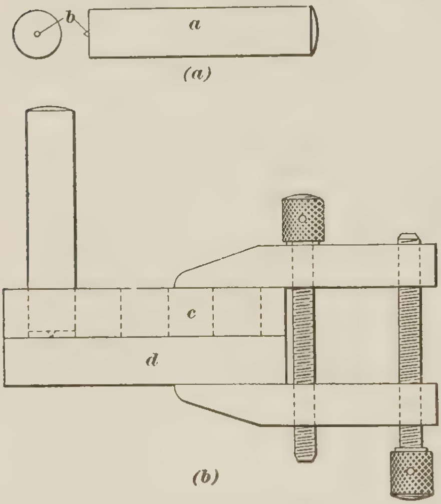


Fig. 22

61. If an error of a few thousandths is permissible, the *scribed-line method* of locating the centers of the holes may be used. In this case the work and model are clamped together, and, the model serving as a templet, the outlines of the holes are carefully scribed on the work. With a pair of dividers the centers of these circles are found and prick-punched. The work is now clamped to a lathe face plate and each prick-punch mark in turn trued up, using an indicator, and the holes are spotted, drilled, and bored to size.

By this method it is difficult to locate and prick-punch the centers of the circles accurately, and thus errors are caused.

62. Accurate Method of Locating Holes.—If an error of one-thousandth of an inch is permissible, a method in which a special prick punch is used and known as the *prick-punch method* of locating the centers may be used. The form of prick punch employed is shown in Fig. 22 (*a*). The body *a* is turned to fit the holes in the model, the center of one end is turned to a point *b*, and the end is hardened. The model *c*, in (*b*), and the work *d* are now clamped together, the punch inserted in the holes in the model, and the work lightly prick-punched by tapping the punch with a hammer. The holes are now bored out on a lathe face plate as in the preceding case. In this instance, again, small errors cannot be avoided. The punch does not fit the holes perfectly, the prick punch becomes somewhat distorted in hardening, and the angle on the point of the indicator is not the same as the angle on the point of the punch, making it difficult to center with perfect accuracy.

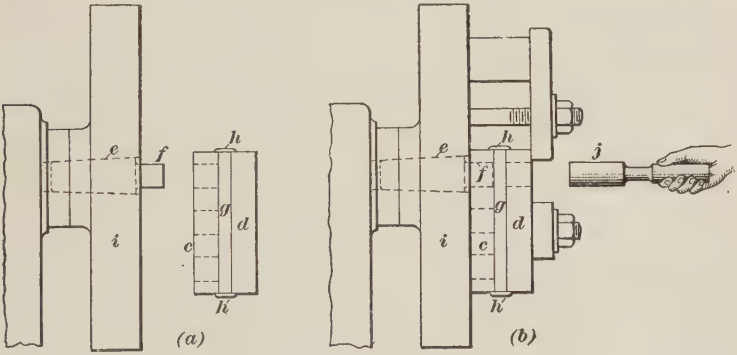


FIG. 23

63. Very Accurate Method of Locating Holes.—For work which must be accurate to, say, .0001 inch, the following method may be used to locate the work on the lathe face plate: A soft-steel center *e*, Fig. 23 (*a*), is turned to fit the taper of the lathe spindle, and is placed tightly in it. The end *f* is now carefully and smoothly turned, without filing, to a wringing fit in the largest hole in the model; that is, the plug fits the hole so that it may just be turned in easily. A parallel plate *g*, the model *c*, and the work *d* are now soldered or clamped together at *h*, wrung on the end *f* of the center, strapped to the lathe face plate *i* as shown in Fig. 23 (*b*), and spotted, drilled, and bored to fit a plug gauge *j*. The plate *g* permits the hole to be bored through the part *d* without injuring the model *c*.

After finishing the first hole, the end *f* of the center is turned, if necessary, to fit the next largest hole in the model, and the operation continued until all the holes are finished. There is small chance of error being introduced in the work when this method is carefully used, the most likely cause of error being an imperfect fit between the center and the hole.

DIVIDING CIRCLES AND LINES

64. The toolmaker is frequently required to divide a circle into a given number of equal divisions. He may be required to make an original index plate, with holes equidistant from the center and each other and piercing the index plate at a right angle to its surface; or, he may be required to space notches equidistant around the periphery of the work; or, to divide a rim by lines or dots into equidistant divisions.

65. Dividing Circles.—In Fig. 24 is shown a piece *a* that is to be pierced by eight holes perpendicular to its surface and equidistant from each other. A circle of approximately correct diameter is scribed centrally on *a*, divided with dividers into the required number of divisions, and drilled and tapped at the points of division for a small machine screw of convenient size. A number of steel bushings or buttons are made having an inside diameter about $\frac{1}{8}$ inch larger than the diameter of the machine screws and an outside diameter of any convenient size. As far as the diameter is concerned, it need not be any particular size; the only thing essential is that all the buttons have the same diameter.

66. The height of the buttons is immaterial; but the top and bottom surfaces of each button must be parallel and in planes at a right angle to the axis of the button. The inside of the buttons does not need to be finished to any extent. The buttons having been made, their size is calipered with a micrometer. This diameter is subtracted from the diameter of the circle on which the holes are to be located; the remainder will be the outside diameter of a narrow ledge *b*, Fig. 24, that is turned centrally with *a′*, a projection on *a*. If the buttons are in contact with this ledge, the distances from the centers of the buttons to the center of the work will be equal. The buttons *c* are fastened by means of machine screws, a smooth washer having parallel sides being placed between the head of each screw and button. Then, each button being in contact with the ledge *b*, the buttons about 90° apart are adjusted until, by calipering over their cylindrical surface, they are shown to be spaced equidistant. Then the buttons located between those just set are adjusted until calipering shows all the buttons to be equidistant.

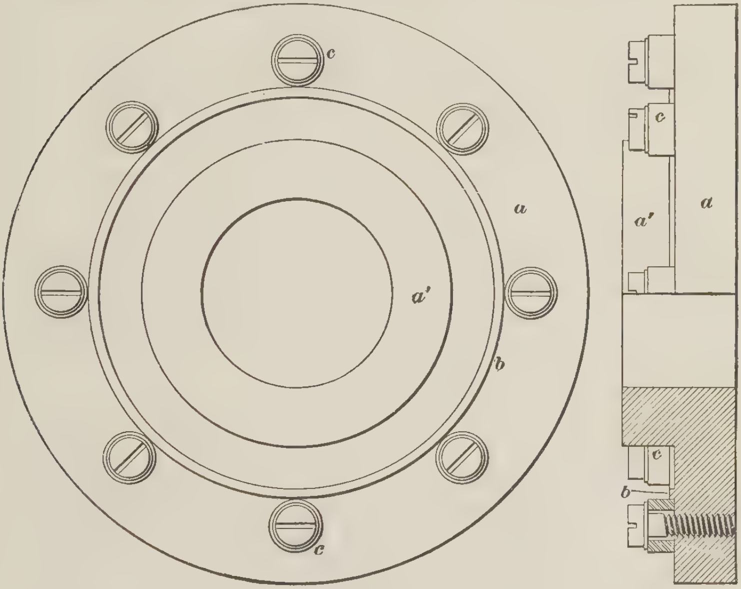


Fig. 24

After each adjustment is made, the screws are tightened sufficiently to prevent any accidental shifting of the buttons. The buttons being properly located, the work is mounted on a true running face plate and shifted until one of the buttons runs true, as shown by a sensitive indicator. This button is removed and the hole is carefully bored. In the same manner, all the other holes are bored.

In this method, the errors that prevent absolute accuracy are chiefly the error made in locating the buttons and the error in truing up by them. However, with careful workmanship and a fairly sensitive sense of touch, a remarkable degree of accuracy can be obtained.

67. Spacing Holes in a Straight Line.—The equidistant spacing of holes that are located on a straight line is the most common application of the division of lines which is presented to the toolmaker. One method of dividing lines is by the use of steel buttons which may be located in a straight line by being brought in contact with a straightedge and placed at the correct center-to-center distance by contact measurements. The work may then be clamped on the lathe face plate, and adjusted until one of the buttons runs true, as shown by an indicator. The button is now removed and the hole is bored to size. This operation is continued until all the holes are bored to size.

TEMPLETS

68. Laying Out.—Templets may be laid out and filed to shape by the toolmaker, or they may be laid out by a draftsman and filed to shape by the toolmaker. If the contour of the templet is composed of straight lines or simple curves or both, it is usually laid out by the toolmaker. In this case the templet is generally made of sheet steel, varying in thickness from $\frac{1}{32}$ to $\frac{1}{8}$ inch, depending on the size of the templet.

When the contour of a templet is composed of irregular curves, as in gear-teeth, the work is sometimes laid out in the drafting room. In this case a soft metal, as zinc or copper, is used, as it is not liable to injure the draftsman's tools and the lines scribed on it show plainly.

69. Let it be required to make a templet to which the work shown in Fig. 25 may be turned. A piece of $\frac{1}{32}$- or $\frac{1}{16}$-inch sheet steel is selected, cut, and filed to about 1 inch by $2\frac{3}{8}$ inches. By referring to the drawing, the required length is found to be $\frac{3}{4}+1+\frac{3}{8}=2\frac{1}{8}$ inches. By making the templet $\frac{1}{4}$ inch longer, $\frac{1}{8}$ inch is provided for clearance on both ends. The work is now taken to the laying-out table and, after chalking or coating with other marking material, the line *a b*, Fig. 26, about $\frac{1}{8}$ inch from the edge of the work, is scribed on it by means of a straightedge and scriber. A light prick-punch mark *c* is made on it at a distance of $\frac{3}{4}+\frac{1}{8}=\frac{7}{8}$ inch from the right-hand edge of the work. To draw a line perpendicular to the line *a b* at *c*, the dividers may be set to about $\frac{3}{4}$ inch and the arcs intersecting the line *a b* at *d* and *e* are scribed. Light prick-punch marks are made at *d* and *e*, the dividers are set to about 1 inch and, using *d* and *e* as centers, the arcs intersecting at *f* are scribed. Using a straightedge and scriber, the line *c f* is drawn. Another way to obtain the line *c f* is to lay a straightedge along the line *a b* and then place a thin try square against the straightedge and scribe the line. To locate the center *k* of the arc *l*, with *d* and *e* as centers and the dividers set to $\frac{1}{2}(1\frac{1}{2}-1\frac{3}{8})=\frac{1}{16}$ inch, the arcs *g* and *h* are drawn. The line *i j* intersecting *c f* at *k* is scribed tangent to these arcs, and a light prick-punch mark is made at *k*. With *k* as a center and the dividers set to $\frac{1}{2}$ inch, the arc *l* is scribed. To obtain the line *u m*, with *c* as a center and the

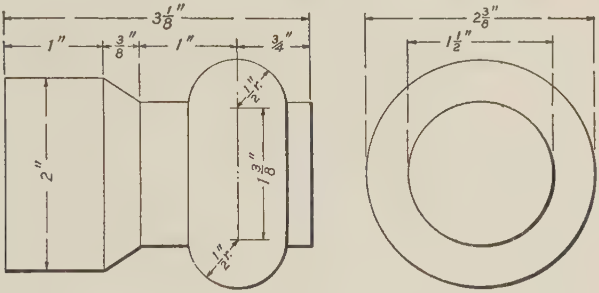


FIG. 25

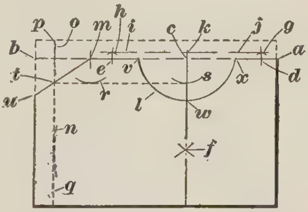


FIG. 26

dividers set to 1 inch, the arc intersecting *a b* at *m* is scribed. With the dividers set to $1+\frac{3}{8}=1\frac{3}{8}$ inches and with *c* and *f* as centers the arcs *n* and *o* are scribed. The line *p q* is drawn, using straightedge and scriber, tangent to these arcs. With *m* and *c* as centers and the dividers set to $\frac{1}{2}(2-1\frac{1}{2})=\frac{1}{4}$ inch, the arcs *r* and *s* are scribed; and, using the straightedge and scriber, the line intersecting *p q* at *t* is scribed tangent to these arcs. Using the straightedge and scriber, the line *m t u* is now drawn. The outline of the templet, *u m v w x a*, is then completed.

Instead of laying out the templet by the method given, two adjacent edges of the stock may first be filed square with each other, and the various lines are then scribed by the use of a try square, the edges filed square to each other being used as working edges.

70. Trimming and Filing.—To sever the work from the stock a series of holes about $\frac{1}{16}$ inch in diameter and running into each other are drilled along the working edge of the templet, care being taken to prevent the drill from cutting into the templet. A sensitive drill press is used for this purpose. In case, after drilling, the holes do not all run into each other, the scrap is severed from the templet by cutting the thin wall of metal joining the holes with a pair of snips. To sever the scrap by chiseling would be bad practice as the metal would be distorted and the layout could not then be depended on.

The work is next gripped in the bench vise, using the copper jaws to protect the work, so that the working edge will be just a little above the jaws of the vise. Using a 6-inch, half-round, bastard file, the edge of the templet is filed nearly to the line, the straight side of the file being used to file the straight edges and the half-round side to file the circular part. A 6-inch, half-round smooth file is now employed to file the templet close to the line, and a dead-smooth file is used to finish the edge by draw filing. The templet is now marked for the purpose of identification, and is ready for use.

NOTICE TO THE STUDENT

READ CAREFULLY BEFORE ANSWERING EXAMINATION QUESTIONS

That the student may understand what is expected in answer to the Examination Questions at the end of each Section, the following examples of questions and answers are given. It will be noted that the answers are short, yet tell all that is asked for in the questions.

In answering the Examination Questions, the student should read each question carefully to make sure that he understands what is required, then write an answer that tells clearly just what is asked for in the question, using his own words as far as possible. By following this plan he will obtain the greatest benefit from his Course. If unable to understand a question, or to answer it after having studied the text carefully, he should write to the Schools at once for help.

Question 1.—Name three points to be considered when selecting materials for toolmaking.

Answer.—Strength, adaptability to form the required shape or bearing surface, and cost.

Question 2.—What is Stub's steel?

Answer.—A high grade of round carbon tool steel that has been rolled cold and very closely to size.

Question 3.—What material makes an excellent belt for a bench grinder?

Answer.—Hollow-woven cotton sleeving, such as is used to cover electric conductors.

Question 4.—What is the procedure in the making of jigs and fixtures for the manufacture of a new article?

Answer.—A working drawing is made of the article, and from this a model is constructed. The model is tested and modified until it meets with approval, and then complete drawings are made to be used in designing the jigs and fixtures, drawings of the latter being made for the toolmaker's use.

Question 5.—What are the limitations of toolmaking?

Answer.—Limitations of accuracy and commercial limitations.

TOOLMAKING

(PART 2)

CUTTING TOOLS

TAPS

FLUTING

1. To provide cutting edges and also a place for the reception of the chips, taps are fluted. Taps up to and including $2\frac{1}{2}$ inches diameter are generally made with four flutes. For larger sizes, practice varies. Some toolmakers advocate five or more flutes for sizes above $2\frac{1}{2}$ inches; others make four flutes on all sizes. Four flutes are usually sufficient and satisfactory for all taps that cut a full thread of the right diameter in one operation. Special taps, or *hobs*, as they are often called, for tapping screw-cutting dies are made with from six to eight flutes; they are not intended to cut a full thread at one passage, but rather to finish out to size the die that has previously been tapped with a slightly smaller tap.

2. **Forms of Flutes.**—Two different forms of fluting are in common use; these are shown in Fig. 1 (*a*) and (*b*). The form shown in (*a*) is considered by many to be the better form, as it makes not only the stronger tap, but also prevents the cracking of the tap lengthwise in hardening, owing to the absence of relatively sharp corners where a crack could start. The curve of the groove is composed of two arcs tangent to each other;

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the large arc, as *b*, may, for a four-fluted tap, have a radius equal to the diameter of the tap, and the small arc *c* may have a radius of one-sixth of the diameter. These proportions are approximate and vary somewhat, not only with different makers, but also on account of the inexpediency of having a different cutter for each different size of tap. In practice, one cutter is made to answer for several sizes.

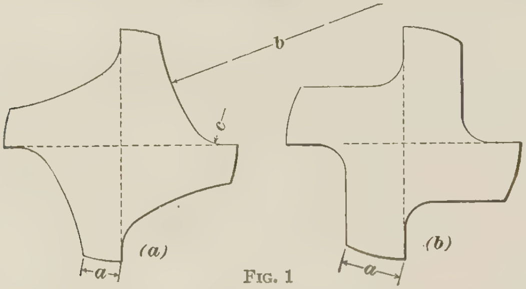


FIG. 1

3. The fluting shown in (*b*) is most commonly used, although it does not make a tap as strong or as easy working as the form shown in (*a*). In order not to weaken the tap too much, the *land* *a* must be left wider than it is in (*a*); a greater friction in tapping is thus produced. The sides of the flute are perpendicular to each other; the corner may have a radius of one-eighth of the diameter of the tap.

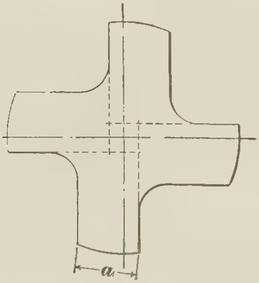


FIG. 2

In both forms of fluting, it is the common practice to make the cutting edges radial, as shown by the dotted lines in Fig. 1. This answers very well for general work. If a tap is to be used entirely for brass, and especially for brass castings, the cutting edge may be slightly advanced so that it will be parallel to a radial line, as shown in Fig. 2. This will give the cutting edge a slight negative rake and cause the tap to cut more smoothly and with less liability to chatter. The amount that the cutting edge is advanced need not be very large; it may be from one-sixteenth to one-tenth of the diameter of the tap. Taps that are to be used for general work on all kinds of metal usually have radial cutting edges.

HAND TAPS

4. As the name implies, hand taps are intended for tapping holes by hand. As it is rather difficult to use the tap without throwing a sidewise strain on it and thereby tapping the hole larger at the end where the tap was started, the construction should be such that it will counteract this tendency as much as possible. This is done by making the lands rather wide and giving no relief to the thread back of the cutting edge. The width of the lands for a four-fluted tap when made with flutes, as shown in Fig. 1 (*a*), may be two-tenths the diameter of the tap. When fluted with four flutes, as shown in Fig. 1 (*b*) and Fig. 2, the width *a* of the lands may be about one-fourth the diameter of the tap. The square on the end of the tap intended to receive the tap wrench is generally placed so that the corners are in line with the cutting edges.

5. Cutting-Off, Centering, and Facing.—Taps are made of round tool-steel or semi-high-speed-steel stock, larger in diameter than the tap size by $\frac{1}{16}$ inch for sizes up to $\frac{1}{2}$ inch, $\frac{1}{8}$ inch for sizes from $\frac{1}{2}$ inch to $1\frac{1}{2}$ inches, and from $\frac{3}{16}$ to $\frac{1}{4}$ inch for sizes larger than $1\frac{1}{2}$ inches. After cutting off the stock to the desired length and before beginning to machine the tap, the stock is thoroughly annealed, preferably in slaked lime, and carefully centered.

The live center is tested by the indicator to find whether it runs true. If not, it is trued up in the usual way. The work is then placed on the lathe centers and the ends *a*, Fig. 3, faced square. The facing is done with a thin side tool, which is set at such an angle that its point may cut clear into the drilled center, the dead center being backed away slightly just as the tool is brought up to it.

6. Turning and Milling.—After cleaning the centers and adjusting the work on them, the part *b*, Fig. 3, is turned to size. A piece of soft metal is put around the part just turned, a dog is fastened to it, and the end *c* is turned to size, after which the square *d* on the end of the tap is milled, the work being held in the chuck or between the centers of the milling machine. On large taps, it is good practice to mill the square before turning the threaded end to size. This square presents a good place to attach the dog.

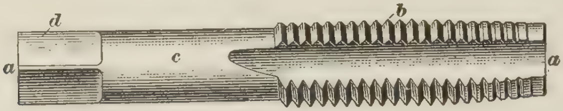


Fig. 3

7. Cutting the Thread.—Cutting the thread is the next operation. Great care must be used to obtain a perfect thread and one of the correct size. The thread is usually chased on a lathe; but in the case of small taps, when accuracy of pitch is not essential, the thread may be cut with a die. If the die is in good condition, a very good thread can be cut if plenty of lard oil is used in cutting; however, as with all dies that feed themselves, the pitch of the thread cut will be coarser than the pitch of the thread of the die.

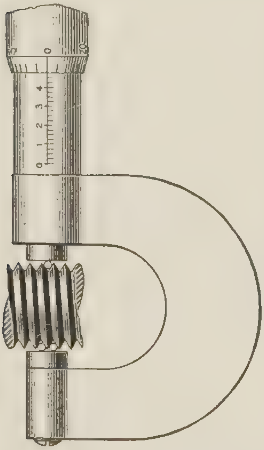


Fig. 4

If a threaded ring gauge of the correct size and pitch is available, the thread is made to fit it perfectly. If, instead of a threaded ring gauge, a model tap or a threaded plug gauge is at hand, the thread is cut so that it will measure the same as the model tap or the plug. This may be done conveniently by placing small pieces of drill rod first in the threads of the model tap or plug of the form and size to be made and then in the threads of the work, and measuring carefully with a micrometer caliper, as shown in Fig. 4. When these measurements are identical, the thread is correctly sized, providing the thread tool is ground exactly to the angle of the thread of the model tap. It is well to measure the thread in this way even when fitting the tap to a ring gauge, as the toolmaker then knows how much more stock must be removed.

8. **Finishing.**—After cutting the thread, the end is chamfered, the amount depending on whether the tap is to be a taper, plug, or bottoming tap. The tap is now fluted in the milling machine, the milling-machine cutter being set by trial to cut the correct depth of flute; large taps may require several cuts.

The flutes having been cut, the cutting edges will have to be filed up a little on the face with a rather fine file to remove the burrs left by the milling cutter, and if the tap is over $\frac{1}{4}$ inch, it may be backed off by filing, or relieved in a lathe by use of the relieving attachment and the same kind of tool that was used in chasing the thread. The chamfered ends must be given clearance by filing. The size, and preferably the number of the threads also, having been stamped on the shank, the threaded portion of the tap is hardened and the temper is drawn to a light straw color, as explained in the making of a plain mandrel. The shank of the tap is not dipped in the hardening bath, as it is desirable to have it remain soft to avoid breakage.

After tempering, the tap is ground with a formed grinding wheel, the tap being held between the grinding-machine centers. Taps are sometimes ground by holding them in the hand against the grinding wheel; but this method produces crooked flutes. There is also danger of touching the points of the teeth with the wheel, thereby either injuring or destroying the tap.

9. **Effect of Hardening.**—If the pitch of the thread and its diameter are measured after hardening, it will usually be found that the pitch and the diameter have changed a small amount. In a few instances, the tap will measure the same as before. This change can be minimized by the selection of the steel, as some steels change very little during hardening; and by slow, careful, even heating, combined with

hardening at as low a heat as will be sufficient to make the tap hard. Fortunately, the amount of change rarely exceeds two-thousandths of the length and diameter, and is negligible for nearly all work.

MACHINE TAPS

10. Machine taps are intended for use in tapping machines, in the turret lathe, and for similar work. Since these taps are intended to be guided axially by attachments, the lands can be made narrower than in hand taps, and relief can be given to the teeth, which causes them to cut more freely. Relief is given by cutting the thread back of the cutting edge until the tap has the form shown in Fig. 5. Very little relieving is necessary; it is not advisable to give too much relief, since, in backing the tap out, chips are liable to be drawn in between the work and the lands.

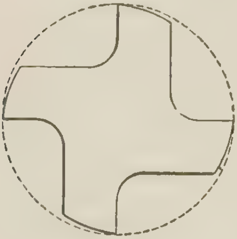


Fig. 5

TAPER TAPS

11. Taper taps may be intended for use in a tapping machine or for hand tapping. In making a taper tap, attention must be paid to two points that are frequently overlooked, and in consequence of which the tap, though finely made otherwise, will produce poor work. One of these points is the relieving of the back of the cutting edge of the teeth, and the other is that a taper attachment must be used. A taper tap must be relieved. A trial of a taper tap not relieved in the thread, especially if the taper is large, will immediately show that the tap, instead of cutting the metal, will squeeze it. The sides of the thread at the back of the lands drag against the work, thus preventing the cutting edges from cutting. The threads are usually backed off with a triangular file; manufacturers of taps use a special machine that relieves the thread in the process of cutting it.

12. To give the tap the correct pitch of thread, it must be cut by a taper attachment. When a taper tap is cut in a lathe not fitted with this attachment, the tailstock center must be set over. Two errors are then introduced that become more pronounced as the taper is made larger. In the first place, the pitch will be finer; in the second place, the thread, instead of being true, will be irregular. Neither of these errors can be readily corrected. The second error is due to the fact that, in taper turning with the tailstock set over, the work does not turn with a uniform velocity, while the cutting tool advances along the work with a uniform velocity.

When the taper is slight, the change in pitch and the irregularity of the thread are ordinarily imperceptible to the eye; with tapers of $\frac{3}{4}$ inch per foot, the errors become noticeable and increase rapidly as the taper becomes larger. For these reasons, taper taps should always be cut with the taper attachment. If none is available, there is nothing left except to set the tailstock over. The thread should then be well relieved; this will make the tap cut free, but will correct neither the pitch nor the irregularity of the thread. In cutting the thread on a taper tap, the threading tool should be set even with the

TABLE 1

ERRORS IN TAPER TAPS

Taper Inch per Foot	Length Along Axis Inch	Taper Inches per Foot	Length Along Axis Inch
$\frac{1}{8}$	.9999	$1\frac{1}{2}$	.9980
$\frac{1}{4}$	.9999	$1\frac{3}{4}$	.9973
$\frac{5}{16}$	.9999	2	.9965
$\frac{3}{8}$	.9998	$2\frac{1}{2}$	.9946
$\frac{7}{16}$	.9998	3	.9922
$\frac{1}{2}$	.9997	$3\frac{1}{2}$	.9895
$\frac{3}{4}$	.9995	4	.9863
1	.9991		

NOTE.—The word *taper* is defined in a different manner by different persons; it will here be taken to mean *the difference in diameters per foot of length measured along the axis.* This definition is in accordance with the most general practice.

center line of the lathe spindle and so that the plane of its face will be parallel to the ways of the lathe.

13. In order that the toolmaker may determine whether the error in pitch introduced by setting over the tailstock is of sufficient importance to prohibit this method, Table I is given. In this table, the figures in the second column represent the length along the center line of the tap, in ten-thousandths of an inch, for 1 inch measured along the surface of the tap. The greater the difference between the dimensions given in the table and 1 inch, the greater will be the error introduced into the work.

HOBS

14. Taps made for cutting the threads in solid and split dies for screw cutting and chasers are called **hobs.** They differ from ordinary taps chiefly in having more flutes; they are usually given from six to eight flutes. When hobs are to be used for *solid* dies, they must, of course, be of exact diameter. When used for dies *adjustable* through quite a range, it is advisable to make them larger. Their diameter may then be twice the depth of the thread plus the nominal diameter of the die. Cutting an adjustable die with a hob larger than the screw to be cut with it, will give relief to the threads of the die back of the cutting edges. In consequence of this relief, which in ordinary dies cannot readily be given in any other manner, the die will cut much more easily and cleanly. Hobs are advantageously used in connection with a leading tap slightly smaller in diameter. The hob is thereby relieved of the severest duty, and hence a smoother and truer thread will be tapped by it.

15. When making a hob, it must always be remembered that the perfection of the screw made by the die for which the hob is intended depends primarily on the hob; and hence it should be made as perfect as conditions permit. Any poor workmanship in the thread of the hob will be duplicated in the die, and usually in a greater degree. A poorly cut die will naturally produce a poor screw thread. When tapping a die with a hob, plenty of oil should be used and care should be taken that the flutes do not become clogged with chips. Some toolmakers do not relieve the hobs intended for straight dies; taper hobs should be relieved for the same reason that taper taps are relieved.

16. Chaser Hobs.—Hobs for making chasers, or hand-lathe tools for chasing threads, or the cutting parts of inserted-blade taps and dies, are made straight. They need not be longer than three times the width of the widest chaser that is to be cut by them, and should be provided with numerous flutes, preferably spaced a little unevenly. As these hobs are to be used between the centers of a hand lathe, they should be provided with liberal-sized centers. They should have shanks long enough to take a dog, and hobs having from 40 to 8 threads per inch should be about 1¼ inches in diameter, with the threaded part about 2 inches long and the shank 1½ inches long. The hob should have about twenty flutes cut with a 60-degree cutter, the cutting edges being radial. Since the excellence of the chaser depends on the hob, the thread should be cut as perfect and smooth as possible. After hardening at a low heat, the temper of the hob is uniformly drawn to a full straw color. When using it, the rest is so adjusted that the height of the upper side of the chaser will be the same as that of the center from the ways of the lathe. The hob will then cut the teeth into the chaser with sufficient relief to make the chaser cut freely. The temper of the chaser is drawn to a pale straw color.

ADJUSTABLE TAPS

17. Forms.—Some forms of adjustable taps will cut a full thread in one passage through the work; other forms are used only for finishing a hole that has previously been tapped by a leading tap of slightly smaller diameter. A very simple form of adjustable tap is shown in Fig. 6. As may be seen, the

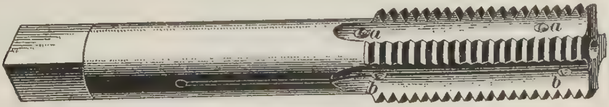


FIG. 6

tap is split. The two halves are held together by binding screws *a*, and the tap is expanded by the taper-headed screws *b*.

18. Another form of adjustable tap suitable for holes that pass clear through the work, or need not be tapped close to the bottom, is shown in Fig. 7. The tap is split longitudinally; the two halves can be forced apart by a screw *a* having a tapering head. After setting it, the two halves of the tap are held together by setting up the nut *b*, which has a beveled recess that engages the conical projection at the front end of the tap. While locking the nut, the central screw must be prevented from turning by inserting a screwdriver into its slot and holding it. The nut may be made hexagonal in form at its front part, as shown, or have radial holes drilled in its circumference. In the latter case, a spanner must be made for it. In making such a tap, it is advisable to cut the thread and flute the tap before splitting it. It may be slotted slightly beyond its threaded part, the slot terminating in a hole drilled perpendicular to the axis.

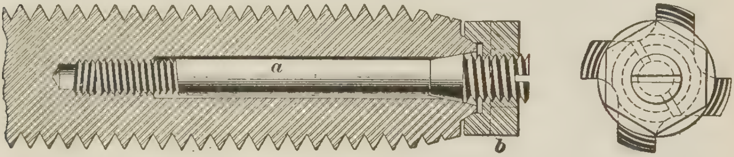


Fig. 7

19. Adjustable taps may also be made as shown in Fig. 8. Four tool-steel blades *a* are inserted in dovetail slots, the bottom of each slot making an angle with the center line, or axis, of the tap. The blades are held lengthwise by two nuts, one at each end. By varying the position of these nuts, the tap

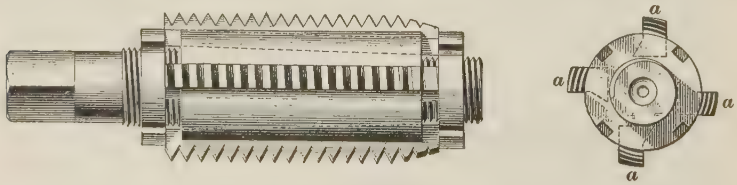


Fig. 8

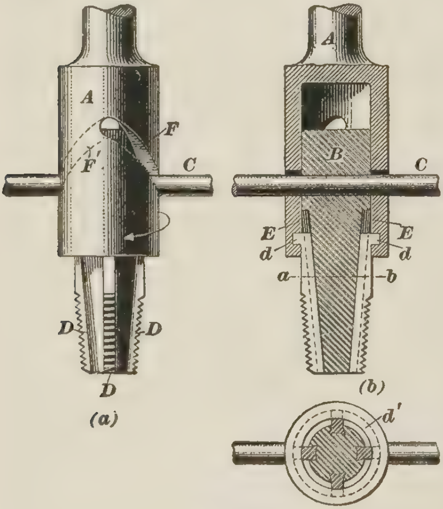
may be expanded or contracted slightly. Taps of this kind cannot ordinarily be made for sizes smaller than 1 inch, since the shank would have to be made too small to provide the necessary stiffness.

20. Making an Adjustable Tap.—In making the tap shown in Fig. 8, the body, which may be made of machinery steel, is turned first; the slots are then cut in the shaper or the milling machine and the square on its end is milled. The diameter of the tap body, at the points where the nuts are located, is now turned small enough to clear the bottom of the slots and a fine thread is cut on each end of the body to receive the nuts. Each of the two nuts are now threaded and faced at the same chucking, in order that the faces will be true with the thread, the nuts being made a good snug fit. The blades may now be milled or planed out of well-annealed tool steel and are made to fit the slots tightly to avoid slipping during facing. In order to make them of equal length, they are driven into the slots and their ends are faced in the lathe. The nuts are now put on; the nut at the shank end is first screwed up until it is within a short distance of the shoulder and the front end nut is then tightened.

After turning the blades to nearly the correct size, the thread is chased on them, and their front ends are chamfered. The nuts are now removed, the blades and the slots are stamped with corresponding marks, the blades driven out, the chamfered parts relieved, and the threads backed off slightly with a fine three-cornered file. The threads require backing off owing to the springing of the tap during thread cutting causing the back edge of each blade to be slightly higher than the front or cutting edge. After relieving, the blades are carefully hardened, and the temper is drawn to a straw color. If the blades should spring very much, they must be straightened before inserting them again. If the body is made of machinery steel, the square at the end may be case-hardened. An adjustable tap is usually set to correct size by actual trial.

COLLAPSING TAPS

21. Purpose.—Taps so constructed that the blades forming the cutting edges can be moved at will toward or from the center, are called collapsing taps. They are used largely for work done in the turret lathe, when the hole to be tapped exceeds 1½ inches in diameter. Their chief advantage is that they need not be turned back to withdraw them from the tapped hole; the blades are drawn in enough toward the center to clear the thread and the tap can then be withdrawn by a lengthwise motion. As a matter of course, nearly all the time required to turn an ordinary tap back is saved. Since a collapsing tap is quite an expensive tool, its use is limited to work done in large quantities.



(a) (b) (c)

Fig. 9

22. Form.—A simple collapsing tap designed for tapping a taper hole in brass castings is shown in Fig. 9 (*a*), (*b*), and (*c*). For this reason, the cutting edges of the blades are advanced in the direction of cutting; that is, they are given negative rake. The shank *A* is fitted to the turret. The end of the shank is bored out cylindrical to receive the tap body *B*, in which four dovetail grooves are cut, to which the blades or chasers *D* are fitted. A circular groove *d'*, shown in (*c*), having a square cross-section, receives the lugs *d* and confines the chasers longitudinally. The body of the tap is prevented from rotating by a pin *C* passing through it. This pin, while the tap is cutting, rests against the lower ends of the helical slots *F* and *F'*. When the hole has been tapped to the desired depth, the pin *C* is turned in the direction of the arrow. The pin follows the helical slots and the body *B* is drawn into the shank; since the dovetail grooves in which the chasers work are at an inclination to the axis, the chasers are drawn together and the tap can be withdrawn. To get it ready for work again, the pin *C* is turned back. A tap of this design may be used in a chuck in the lathe. When used for a turret lathe, it is almost always necessary that the hole be tapped to the same depth in every piece operated on. If this is the case, it should be used in connection with a releasing tap holder.

23. Making Collapsing-Tap Shank.—When making a collapsing tap of the kind shown, the only thing that may prove difficult will be the two helical slots in the shank. They are rather difficult to produce by hand, but if care is taken to use a helix that can be cut in the universal milling machine by an end mill, the slots are easily cut. The helical slots may also be cut by drilling holes the proper distance from the end of the shank to locate the ends of the slot. The lathe is then set to cut a thread having the pitch of the helix, and a side tool is set up in the tool post. The lathe is rotated by hand while the tool cuts the slot.

Collapsing taps may be made in a variety of designs to suit different kinds of work. Thus, where bottoming holes are to be tapped, the blades may be arranged to collapse by means of a centrally located movable stop within the tap body coming in contact with the bottom of the hole; the stop when moving back then draws the blades inward.

RELEASING TAP HOLDERS

24. Purpose.—In screw-machine and turret-lathe work, when holes are to be tapped to a uniform depth, a tap holder should be used that will automatically release the tap from the holder as soon as the hole has been tapped to the proper depth. Such a holder will allow of rapid tapping, and, when properly adjusted, prevents breakage of taps by striking the bottom of the hole.

25. Example.—A very common and highly efficient releasing tap holder is shown in Fig. 10; it is especially adapted to screw-machine and turret-lathe work. It consists essentially of two pieces. The sleeve *a* fits one of the tool holes of the turret. The tap holder *b* is free to slide longitudinally within the sleeve a certain amount; when the stop pins *c* and *d* are disengaged, the holder *b* is free to rotate within the sleeve. The end of the tap-holder shank carries the backing-out pin *e*, which is so located that when the clutch pins *c* and *d* will just clear each other, it will be from $\frac{1}{8}$ to $\frac{1}{4}$ inch away from the helical end of *a*. The end *b* of the tap holder may be made in a variety of ways to suit the purpose. The simplest way is to make it as shown; the tap shank fits the hole and is held from turning by the setscrew. If thus made, its use is obviously limited to taps having the same shank diameter. To make it adapted to all sizes of taps, the end *b* may be a universal chuck; the holder then becomes a *universal* releasing tap holder Or, the end *b* may be made large enough for the largest size of tap to be used in it and bushings made for the smaller sizes.

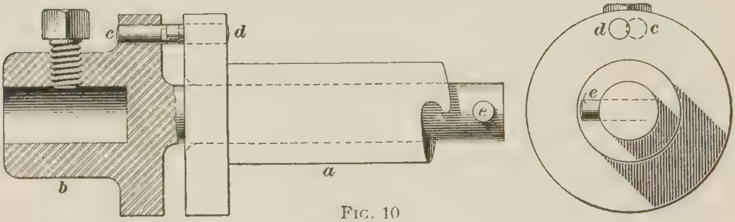


FIG. 10

26. Operation.—The sleeve *a*, Fig. 10, being fastened in the turret, the stop-pin *c* butting against the flange of *a*, and the stop-pin *d* preventing *b* from turning, the slide of the turret is advanced and the tap engages the revolving work. As soon as the turret slide comes against its stop, the tap, which has entered the work, is drawn forwards until *c* and *d* are disengaged, when it is free to revolve. This stops further tapping. The spindle of the machine is now reversed, which causes the work, and hence the tap, to turn in an opposite direction. The turret slide is then withdrawn; the backing pin *e* during the backward motion is guided by the helical end into the recess of the sleeve shank, and any further turning of the tap is thus stopped. The tap is thus backed out by the revolving work.

27. Proportions.—The diameter of the sleeve shank is fixed by the size of the holes in the turret for which it is intended, as is also its length. The shank of the tap holder may be about five-eighths the diameter of the sleeve shank. The three stop-pins may have a diameter equal to about one-third the diameter of the tap-holder shank. For small work, it is usually advisable to make the whole device of tool steel.

28. Forming Helical End.—When making a releasing tap holder, it is well to remember that the helix at the end of the sleeve shank must be right-handed for a right-hand tap and left-handed for a left-hand tap. The pitch of the helix may be about one and one-half times the diameter of the backing-out pin *e*. The helix is most readily produced in the lathe, gearing the lathe to give the proper pitch and using a square-nosed tool for cutting the helix. A line may first be scribed to mark the position of the helix and then most of the stock removed by drilling and chipping, finishing the groove with the lathe tool.

SQUARE-THREADED TAPS

29. Square-threaded taps may be fluted in the same manner as **V**-threaded taps. When chasing the thread, the usual precautions in grinding the tool and cutting square threads must be observed. If intended to cut a full thread in one operation, the lands must be well backed off, otherwise the amount of force required for tapping will be excessive. When used merely for sizing holes in which the thread has been roughed out, very little backing off is necessary.

30. In tapping square threads several taps are sometimes used in a set, especially where the hole is small and the pitch of the thread coarse. When the hole is long the flutes in the ordinary tap are too small to carry off the cuttings, hence more taps are used, taking smaller cuts and having larger flutes.

Sometimes as many as six taps are used in a set, and if they run with plenty of oil they will clear themselves readily, cut more rapidly, and last longer without dulling. The first tap is sometimes a **V**-thread tap with the correct pitch, and the other taps take out the balance of the stock, gradually approaching the square shape until the correct size and form is reached.

31. Where square-threaded taps do not readily clear themselves of chips, it has been found advantageous to remove some of the teeth, or lands, of the tap. Sometimes every other tooth is removed, and even more than half may be removed with good effect. This is especially true when cutting square threads in brass. The reason for this is that when there is little difference in the height of the cutting edges, they sometimes rub over the surface of the brass with a glazing effect, making the cutting more difficult. Removing part of the teeth reduces the cutting surface and permits the others to do more effective service.

LEFT-HAND AND MULTIPLE-THREADED TAPS

32. Left-Hand Taps.—If a left-hand tap is required, it may be designed and made in the same manner as a right-hand tap, except that the flutes are to be cut in a way the reverse of that used for a right-hand tap. All remarks previously made regarding the number of flutes and the backing off of the lands apply to left-hand taps as well. It is a good plan to stamp left-hand taps with a large **L** on the shank. to call attention to the fact of their being left-hand. This is to be done not on account of machinists not being able to detect the difference, but rather on account of unskilled helpers failing to distinguish between right-hand and left-hand taps.

33. Multiple-Threaded Taps.—Occasionally, multiple-threaded taps are required. If these are intended to cut a full thread in one operation, the lands back of the cutting edges must be well relieved to allow the tap to cut freely; if this is not done, the force required for tapping may be sufficient to break the tap. Generally speaking, it is better to rough out the threads in the hole to be tapped with a lathe tool and use the tap for finishing the thread only.

DIES FOR THREAD CUTTING

CUTTING EDGES

34. Number.—It is now the universal practice to give dies four cutting edges for all sizes up to and including 4 inches. Beyond that size, practice varies. Some toolmakers advocate five cutting edges for dies above 4 inches; others prefer four cutting edges for all sizes. There is no particular objection to making large dies with five or more cutting edges except that it slightly increases the first cost.

The only instance where it is absolutely necessary to give more than four cutting edges to a thread-cutting die is that in which part of the circumference of the work to be threaded is cut away. More cutting edges are then needed to steady the die and thus prevent crowding into the work on the side where the metal is cut away. The number of cutting edges may then be as given in Table II:

TABLE II

CUTTING EDGES FOR SCREW-CUTTING DIES

Circumference Cut Away	Cutting Edges
none	4
$\frac{1}{24}$	5
$\frac{1}{12}$	6
$\frac{1}{8}$	7
$\frac{1}{6}$	8

When more than one-sixth of the circumference is cut away dies usually will fail to cut a satisfactory thread.

By the size of a die is meant the diameter of the screw it will cut; thus, a die that will cut a $1\frac{1}{2}$-inch screw is called a $1\frac{1}{2}$-inch die, irrespective of the outside diameter of the die itself.

35. Rake.—For general work and for dies that are to be used indiscriminately for iron, steel, brass and other copper alloys, the cutting edges should be made radial. For dies that are to be used entirely on brass castings, the cutting edges may recede somewhat from a radial line, thus giving a slight negative rake.

NON-ADJUSTABLE DIES

36. Solid Dies.—Owing to the difficulty of sharpening the cutting edges, and of making them to an accurate size, solid dies—that is, dies made from one piece—are used comparatively little nowadays in machine-shop work. Being inexpensive in comparison with adjustable dies, they may sometimes be employed with advantage for special work when only comparatively few threads are to be cut and no great accuracy as to size is required.

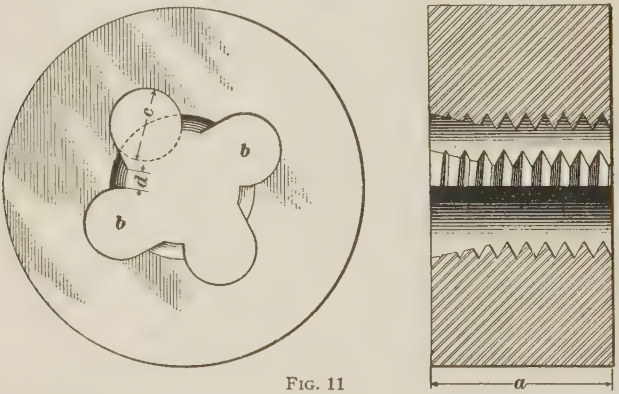


FIG. 11

37. The die may be made as shown in Fig. 11. The die illustrated is round, being intended for use in the die holder of a screw machine. It may be made of any other form, however. The outside diameter of a solid die is usually fixed by the diameter of the holder for which it is intended, but should not be made less than 2.5 times the diameter of the screw it is to cut. The depth *a* of the die may be one and a quarter times the diameter of the screw, and slightly more for very small screws, such as machine screws. If four cutting edges are used, the clearance holes, as *b*, should be spaced equidistant and with their centers on a circle having a diameter equal to the diameter of the screw to be cut. The diameter *c* of the clearance holes is usually made one-half the size of the die, and the top *d* of the lands about one-twentieth the circumference of the circle tangent to the lands. The cutting end of the die is to be chamfered out about three to four threads deep, as shown in the cross-section. The chamfered parts must be relieved in order to give keen cutting edges.

38. The usual way to make the die shown in Fig. 11 is to cut the thread in the lathe, provided the die is large enough to permit this to be done. Since it is very difficult to measure an internal thread, a thread-plug gauge of the required diameter and pitch of thread is first made, unless a tap is in existence that will serve as a thread-plug gauge. The thread having been cut, the beginning of the thread in the die is chamfered while still in the chuck. A piece of steel is now screwed in the full length of the die and faced off flush with the faces of the die. The temporary thread-plug gauge previously mentioned may be used for this purpose when only one special die is to be made. The centers of the clearance holes are next laid out on the back face of the die and these holes are drilled. After drilling the first hole, a tight-fitting plug is inserted in the clearance hole just drilled, to prevent the screw within the die from turning while drilling the other clearance holes. After drilling, the screw is removed and the back edges of the lands are finished by filing. The cutting edges are now filed carefully with a fine file to remove the burrs, the chamfered parts are relieved, the die is hardened and its temper is drawn to a straw color. Owing to the fact that the insertion of the piece of steel in the threaded part of the die is apt to stretch the soft thread, the holes *b*, Fig. 11, are sometimes cut by first drilling small holes, and then finishing them to size by the use of a counterbore.

39. When a large number of solid dies of the same size are to be made, it is cheaper to cut the thread by tapping, finishing with a hob of correct size. In this case, the chamfering may be done with a suitable taper reamer prior to tapping, and the clearance holes drilled in a jig; with a substantial jig, if the drilling is carefully done, there will be no need of inserting a screw in the tapped hole. The holes in the jig will steady the drill sufficiently for drilling. For rapid finishing of the clearance spaces, a hardened filing jig will be found of great service. The thread is now cleaned up by running the hob through the die and the chamfered cutting edges are relieved by hand filing. While relieving can be done by special tools, this will rarely pay except when the number of dies is large. When only one die of a special size or pitch of thread is to be made, it will scarcely pay to make a hob for cutting the thread.

40. Inserted-Blade Dies.—When dies are required for screws larger than 2 inches, it is usually advisable to make them

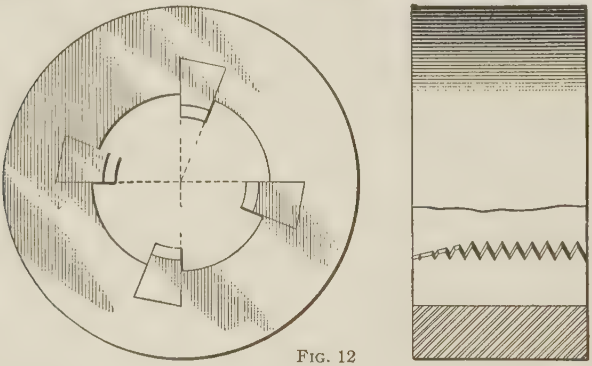


FIG. 12

with blades inserted in a ring of cast iron, wrought iron, or machinery steel as shown in Fig. 12. There are three advantages gained by this construction. First, all danger of losing the die by cracking while hardening is obviated; second, the die can be readily sharpened, since the blades are removable; and third, after the ring or die body is once made, new blades can be made at a fraction of the cost of a solid die. The first cost of an inserted-blade solid die of small size is probably a little higher than that of a solid die up to $2\frac{1}{2}$ inches in diameter; above this size, the inserted-blade solid die is usually cheaper to construct and will give better satisfaction on account of ease of sharpening and repairing.

41. For dies larger than 2 inches, the following proportions will serve as a guide, where d = diameter of screw; outside diameter of die body = 2.4 to 2.5d; inside diameter of die body = 1.3d; length of blade = 1.25d; width of lands, when four blades are used, as is recommended for general work, about one-sixteenth the circumference of the screw to be cut. When more blades are used, the lands must be made narrower. If the nature of the work demands it, the blades of an inserted-blade die may project somewhat beyond the faces of the die body. They should not project more than the width of the lands, however; otherwise, they are liable to break off under the strain of cutting.

42. In making the dies shown in Fig. 12, the blade holder is finished first, the sides of the dovetailed slots being planed radially. The dovetailed blades are then fitted to these slots, being made a driving fit therein. The blades are then faced flush with the sides of the holder; the thread is cut in the lathe; the beginning of the thread is chamfered off for three to four threads, as shown in the partial cross-section; and the blades, after being properly marked, are driven out. They are then relieved on the chamfered part, hardened, tempered, and driven home again in their proper places as marked.

ADJUSTABLE DIES

43. A great variety of adjustable dies is made for general work. Since special sizes for use in the ordinary die stocks can be obtained of the makers for less than they can generally be made in the tool room, the toolmaker is rarely called on to make them. If such should be the case, there are generally dies at hand that will serve as a guide in making a special die.

44. Use and Proportions of Spring Dies.—In many cases spring dies, Fig. 13, for screw-machine work are, for various reasons, made in the tool room, although they may usually be bought more cheaply from concerns making a specialty of taps and dies. These dies are always used with a clamp collar that serves to adjust them.

Average proportions of spring dies are given in Table III. The proportions given are intended only as a guide, and hence, may be departed from to some extent to suit special requirements.

The length of the threaded part may be about one and one-quarter times the diameter of the screw to be cut. When spring dies are to be used for work whose circumference is partly cut away, the number of cutting edges may be made as given in Table II. The spring die is probably the cheapest adjustable die for screw-machine and turret-lathe work up to and including 2 inches in diameter, as far as first cost is concerned. When threads larger in diameter are to be cut, the use of some form of adjustable die with inserted blades is usually more economical.

TABLE III

SPRING-DIE PROPORTIONS

Size of Screw Inches	Outside Diameter Inches	Length Inches
$\frac{1}{8}$ to $\frac{1}{4}$	$\frac{1}{2}$	1$\frac{1}{4}$
$\frac{1}{4}$ to $\frac{3}{8}$	$\frac{3}{4}$	1$\frac{3}{4}$
$\frac{3}{8}$ to $\frac{1}{2}$	1	2
$\frac{1}{2}$ to $\frac{3}{4}$	1$\frac{1}{4}$	2$\frac{1}{2}$
$\frac{3}{4}$ to 1	1$\frac{3}{4}$	2$\frac{3}{4}$
1 to 1$\frac{1}{4}$	2	3
1$\frac{1}{4}$ to 1$\frac{1}{2}$	2$\frac{1}{2}$	3$\frac{1}{2}$
1$\frac{1}{2}$ to 1$\frac{3}{4}$	3$\frac{1}{4}$	4
1$\frac{3}{4}$ to 2	3$\frac{1}{2}$	4$\frac{1}{4}$

45. Making a Spring Die.—When a spring die is to be made, it should be fitted to one of the clamp collars at hand, thus saving the expense of making a new clamp collar. Spring dies have four cutting edges for general work, the length of the lands being about one-sixteenth of the circumference, and are chamfered a length of about three to three and one-half threads. The die may be first tapped with a tap a little under size, and then with a hob the same size as the screw to be cut. For forming the cutting edges, a 45° milling cutter that will split the die as shown in Fig. 13 is used. Should the die have more than four cutting edges, a cutter whose edges form a different angle must be selected. After splitting the die, the burrs thrown up on the threads may be removed by running the hob through again. The cutting edges are finished by filing with a fine file; the chamfered edges are relieved by hand filing; and the size and the number of threads are stamped on the die, which is then hardened as far as the end of the thread and drawn to a deep straw color.

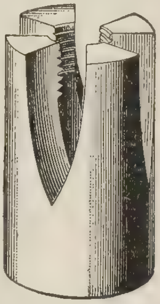


Fig. 13

For accurate, uniform threads, two dies must be used, one for roughing out and the other for the finishing cut. To do good work, the cutting edges must be kept sharp; dies made as shown in Fig. 13 can readily be sharpened by grinding the face of the lands on a suitable grinding wheel.

46. Screw-Adjusting Die.—A large number of the dies in use today are of the screw-adjusting type, one form of which is shown in Fig. 14. When this die is used, the setscrews of its holder will lock the die firmly together. In making the die, the thread is chased; the four clearance holes *a* and the hole *b*, which weakens the connection between the two halves of the die to allow it to be opened easily, are then drilled; a hole is drilled and tapped in the body *c* to receive a tapered set screw *d*; the slot *e* is milled, and the threaded portion is finished as explained in the making of a solid die.

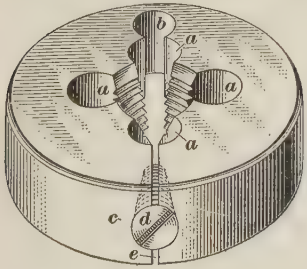


Fig. 14

47. Inserted-Blade Adjustable Die.—One of the simplest designs of an adjustable die with inserted blades is that shown in Fig. 15. The blades are inserted exactly as in the die shown in Fig. 12; the die body is then split, as shown, and an adjusting screw put in. For very large dies, two adjusting screws may be provided, locating each near one of the faces. The drilling and counterboring of the hole for the adjusting screw may be done in a jig if a large number of dies are to be made; in case of a limited number, it may be done in a milling machine, strapping the die body to the milling-machine table. Feeding carefully with an end mill of correct size, the work is counterbored without much trouble. Spotting and drilling are then done while the die body is still strapped down, holding the tools in the chuck. If the die body has been split prior to drilling the hole for the adjusting screw, an iron or wooden shim should be inserted in the slot when milling and drilling.

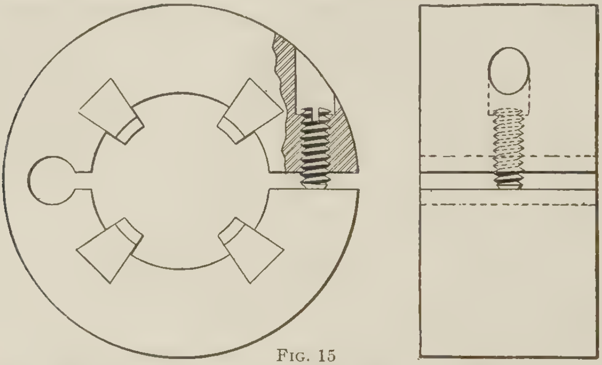


FIG. 15

DIE HOLDERS

48. Releasing Die Holder for Short Work.—For screw-machine and turret-lathe work, solid and adjustable dies are inserted in releasing die holders made on the same principle as a releasing tap holder. The die is held in the holder by three or four pointed setscrews that enter conical depressions, as shown in Fig. 16. These depressions are so located that the tightening up of the setscrews will draw the die against the shoulder of the holder. The length of the die holder naturally depends on the length of the screw to be cut. One or two liberal-sized openings should be cut through the holder back of the die, to provide for free escape of the chips. Practical considerations prohibit the use of the holder shown for very long screws. For these a releasing holder may be constructed in a somewhat different manner, retaining the same principle of releasing and clutching for backing the die off the work.

49. Releasing Die Holder for Long Work.—A design for a releasing die holder for long work is shown in Fig. 17. It consists essentially of two parts, a shank *a* to fit the turret and a die holder *b*. The clutching and releasing mechanism is contained in the front part of the device. For releasing, two stop-pins are employed; the one is driven into the holder and the other into the shank, as shown. The forward part of the shank is enlarged and grooved to receive the end of the backing pin *c*, which in the design here illustrated is firmly screwed into the holder proper. The forward side of the cylindrical groove forms a helix that serves to guide the backing pin into its place. The die holder is bored to be a good sliding fit on the front end of the shank. In the position shown, the clutch pins are disengaged and the holder is free to rotate about the shank. If the turret is now withdrawn while the work just threaded is revolving in a reverse direction, the backing pin *c* is guided into place, clutches the shank, and the die is unscrewed from the work. The shank has a hole drilled through it to admit the threaded work.

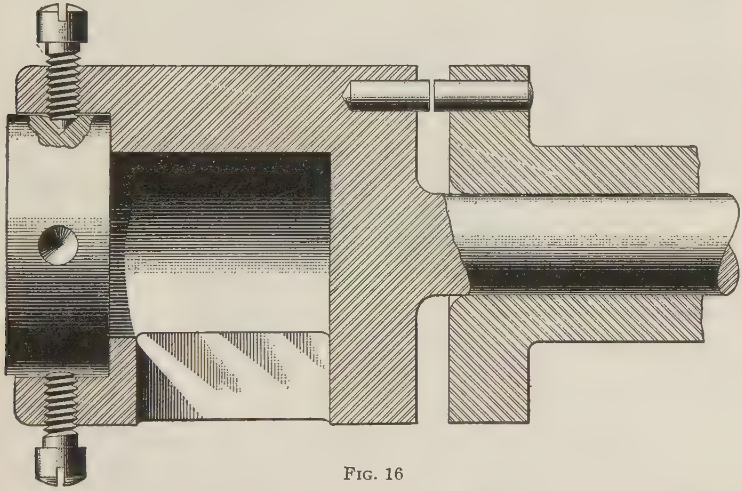


Fig. 16

50. If the die holder is to be used for a right-hand die, the helical side of the groove must be right-handed, that is, as shown in Fig. 17. For a left-hand die, it must be left-handed. If desired, the device may be adapted to both right-handed and left-handed threads. To do this, the enlarged end of the shank is made long enough to receive two grooves; the front side of one groove is then made a right-handed helix, and the front side of the other a left-handed helix. A hole to receive the backing pin is drilled and tapped for each groove; the backing pin may then be changed from one groove to the other, as desired, and a blank screw may be provided to fill the backing-pin hole not in use. One or two openings for the escape of chips are cut in the die holder. The helical side of the groove is most conveniently cut in an engine lathe geared to the correct pitch, which may be about one and one-half times the diameter of the backing pin.

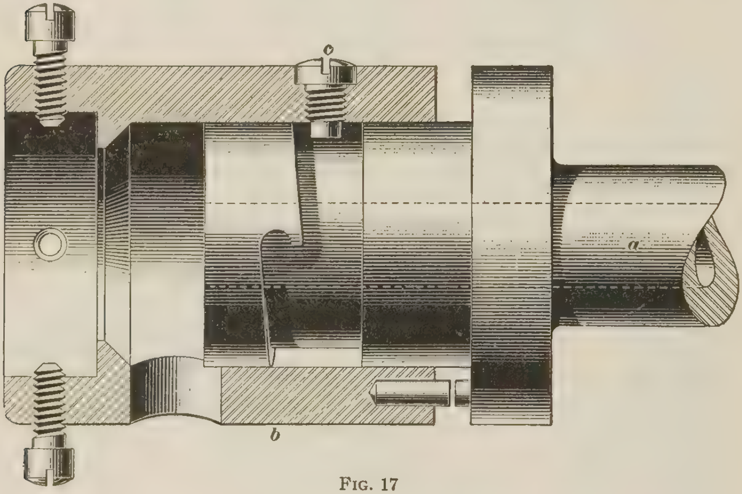


Fig. 17

REAMERS

CLASSIFICATION OF REAMERS

51. Reamers may, in accordance with their shape, be divided into three general classes, *straight reamers*, *taper reamers*, and *formed reamers*. Each of these classes may be divided into three subclasses, in accordance with their construction. These are *solid reamers*, *inserted-blade reamers*, and *adjustable reamers*.

Reamers are generally intended for the production of round smooth holes of accurate size. In some cases, they are merely intended to enlarge holes without particular reference to the holes being true and straight. To produce round and smooth holes, reamers must have their cutting edges spaced and formed correctly. It must not be inferred, however, that there is but one correct way of spacing and forming the cutting edges; the required result may be arrived at in various ways.

STRAIGHT REAMERS

52. Chattering.—Chattering, which is a common fault of reamers, is in itself an evidence of incorrect design or construction of the reamer. It is due to several entirely preventable causes, any one of which, when present alone or in combination with one or more of the others, will induce it. Whether a chattering reamer can be cured or not, depends on its design and construction.

A knowledge of the causes that induce chattering of a reamer will indicate whether it can be cured or not. The causes of chattering are as follows:

1. Equidistant spacing of the cutting edges.
2. Excessive front rake of the cutting edges.
3. Excessive clearance of the lands.

If the cutting edges are spaced equidistant around the circumference, each edge will follow in the track of the others. This condition is not conducive to the production of a round hole. Excessive front rake will cause the reamer to cut too freely, or "dig in," as it is called. This prevents the production of a smooth hole, since smoothness can be attained more readily by a scraping cut. Excessive clearance, or relief, of the lands robs the reamer of their support; consequently, it works unsteadily and with a wobbling motion.

53. Spacing of Cutting Edges.—Two different systems of spacing are in general use, either of which will tend to prevent chattering. One system is shown in Fig. 18. In this, the cutting edges are spaced irregularly and no two edges are diametrically opposite each other. To show clearly the irregularity of the spacing, a supplementary dotted circle has been drawn and divided into equidistant divisions. Since no two edges are opposite each other, the diameter of the reamer cannot be measured by calipering and it can only be brought to size by fitting it to a ring gauge of correct size.

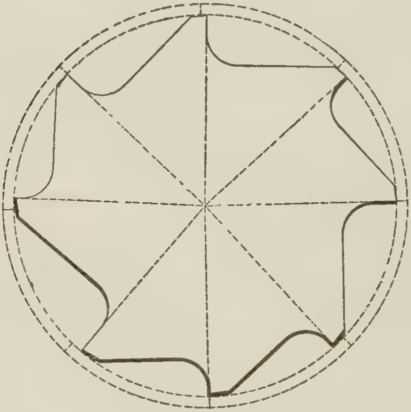


Fig. 18

54. To make it possible to caliper the reamer and at the same time avoid chattering, the system of spacing shown in Fig. 19 is recommended. Here the spacing is so arranged that any two opposite cutting edges are on the same diameter, while no two consecutive edges are equally spaced. While Figs. 18 and 19 show a section of a solid reamer, the methods of spacing shown apply to inserted-blade and adjustable reamers as well.

55. Number of Cutting Edges.—Fluted reamers for lathe and hand work, with the exception of rose reamers and special reamers designed to rapidly remove a large amount of metal, are rarely given less than six cutting edges. For solid reamers, the number of cutting edges may be as given in Table IV.

Generally speaking, there is nothing to be gained by giving a larger number of cutting edges than that mentioned in the table.

56. In inserted-blade reamers, the largest number of cutting edges that can be given depends on the thickness of the blades. They are usually made with less cutting edges than solid reamers. Many people believe that a reamer must have an odd number of cutting edges in order to work well. As far as truth, ease of working, and smoothness are concerned, it does not make the slightest difference with properly formed reamers whether the number of cutting edges is odd or even. As the reamer may be calipered, an even number of cutting edges is really preferable. Rose reamers may be given from three to seven flutes, according to size. In the small sizes, they may be made without teeth between the flutes, and, in the large sizes, may have one or two teeth between each flute, as shown in Fig. 20.

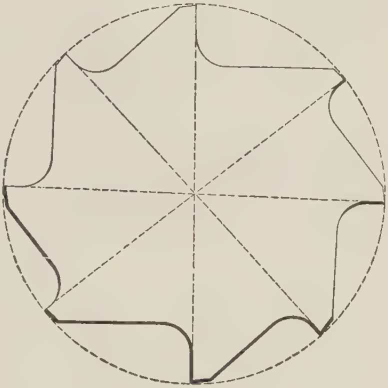


FIG. 19

TABLE IV

CUTTING EDGES FOR REAMERS

Diameter of Reamer Inches	Number of Cutting Edges
$\frac{1}{8}$ to $\frac{1}{2}$	6
$\frac{1}{2}$ to 1	8
1 to $1\frac{1}{2}$	10
$1\frac{1}{2}$ to $2\frac{1}{4}$	12
$2\frac{1}{4}$ to 3	14

57. Forms of Flutes.—A very satisfactory form of flute, shown in Figs. 18 and 19, leaves the reamer very strong and also by the absence of a sharp corner reduces the possibility of the reamer cracking in the corner of the flutes in hardening. Another good form of flute is that shown in Fig. 21. This form gives a greater clearance space than the flute with sides at right angles to each other. Milling-machine cutters for this form of flute are to be set so as to give a slight negative rake to the cutting edge. To allow the negative rake to be seen plainly, two dotted diameters have been drawn in Fig. 21. When using this form of flute, the cutter must be set to such a depth that the land will be about one-fifth the average distance from one cutting edge to the next. If the flute is cut deeper, the cutting edges become too springy for good work. When flutes of the form shown in Figs. 18 and 19 are used, the lands may be about one-eighth the average distance from one cutting edge to the next.

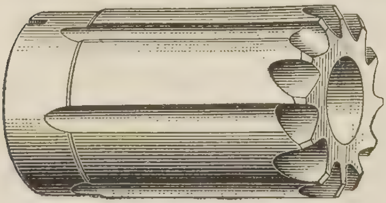


Fig. 20

In general, a reamer will work more smoothly if the cutting edge is given a slight negative rake, since it will then take a scraping cut. The amount of negative rake need not exceed that shown in Fig. 21, which is about 5°. If the reamer is to be used entirely for steel, the cutting edges may be radial, as seen in Figs. 18 and 19.

58. Clearance for Reamers.—In order that the reamer may cut freely, the lands must be relieved back of the cutting edge. This relief can be given either by grinding or by oil-stoning. The amount of clearance necessary depends on the purpose of the reamer. If it is to be used for roughing out, the clearance should be more than is given to a finishing reamer. It should be least for a finishing reamer that is intended to keep its size for a long time.

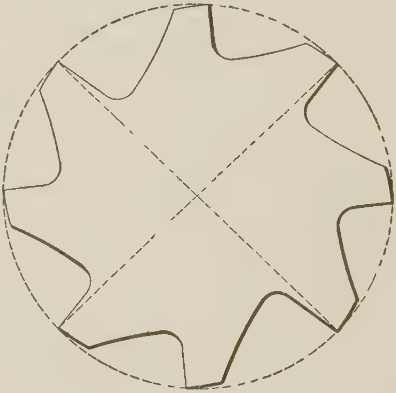


Fig. 21

Fig. 22 shows the appearance of reamer teeth properly relieved for different purposes. The relief to be given to a roughing reamer is shown in (*a*). If the lands are thus relieved, the reamer will cut freely, but cannot be expected to make as true a hole or last as long as the reamer having its teeth relieved as shown in (*b*). This latter form of relief leaves the cutting edge better supported, and consequently the reamer will work more smoothly and keep its size longer than with the form shown in (*a*), but will not cut as freely. In (*c*) is shown the form of clearance to be adopted when the wear of the reamer must be reduced to a minimum in order to produce a large number of holes of the same size. As shown, the land is backed off on the arc of a circle. The amount of clearance at the back edge is made the same as in (*b*); but, owing to the circular form of the relief, the cutting edge is better supported. If desired, roughing reamers may be backed off on the arc of a circle.

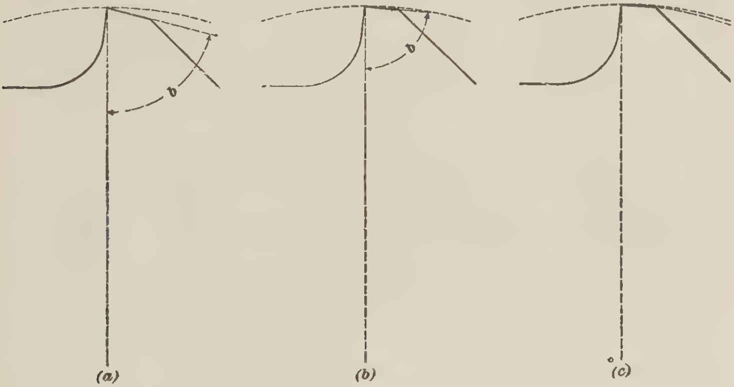


FIG. 22

The amount that the back edge of the land should clear cannot be definitely expressed by any simple rule, since it depends on several variable factors. As an aid in deciding what clearance to give, it may be stated that, for a roughing reamer, the angle *b*, Fig. 22, may be about 80°. For a finishing reamer, the angle *b* may be from 85° to 88°, the smaller angle being used for brass, which generally requires more clearance.

59. Shell Reamers.—The same number of teeth may be given to shell reamers and their cutting edges formed in the same manner as any solid reamer. In making a shell reamer, the hole should be made slightly smaller and then ground to correct size after hardening and tempering. The hardening process will probably change the diameter of the hole, and is sure to throw it out of round; hence, in order that the reamer may fit its arbor well, the hole must be ground. The cutting edges may then be ground while the reamer is mounted on its arbor.

60. Rose Reamers.—As rose reamers cut on the end only, the grooves with which they are to be provided along their cylindrical surface need not be of the same shape as those of other reamers. A semicircular milling cutter having a width equal to about one-quarter the diameter of the rose reamer will cut an excellent groove, the depth of which may be about two-thirds the width of the cutter. After hardening, tempering, and grinding the cylindrical part truly circular, the extreme cutting edges are trued up and brought to a sharp cutting edge by careful grinding on a beveled grinding wheel, or by oilstoning.

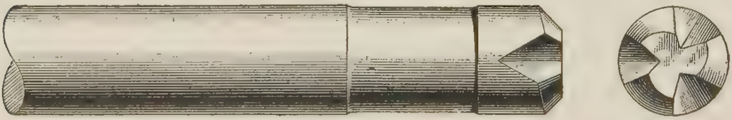


FIG. 23

Rose reamers for small work can be made advantageously of drill rod, which can be obtained very closely agreeing with the diameter corresponding to its nominal size. Commercial drill rods in sizes up to No. 1, drill gauge, will rarely vary more than .001 inch from its true size and be surprisingly straight. Such small rose reamers are often made without flutes, and answer quite well where extreme accuracy is not required. Furthermore, they are quite cheaply made in a speed lathe and, since they are hardened only at the end, need no grinding for ordinary work.

61. When making small reamers from drill rod, they should be necked down back of the cutting edge, as shown in Fig. 23; the diameter at the neck may be from .002 to .004 inch smaller than the rod. When hardening drill rod at the end, it will often swell—that is, become slightly larger in diameter—directly back of the hardening. By necking down the rose reamer where the swelling is likely to occur, any danger of having the reamer bind in the hole is obviated.

Rose reamers made of drill rod up to and including No. 1 gauge size may be given three cutting edges. After beveling the end of the reamer in the lathe, the flutes may be milled or filed in with a three-cornered file. The teeth should be formed as illustrated in Fig. 23, which has purposely been enlarged to show the cutting edges clearly. If thus made, the reamer, while cutting, will tend to push the chips ahead; this feature contributes to the smoothness of the hole reamed by it, since there is little danger then of the flutes becoming clogged. After giving clearance to the cutting edges, harden at the very end and temper. A very smooth hole can be obtained if the outer corner of each cutting edge is slightly rounded over with an oilstone.

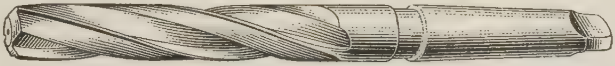


FIG. 24

62. Chucking Reamers for Roughing.—While rose reamers are sometimes used in screw machines, chucking machines, and lathes for roughing out cored holes, other forms of reamers are better adapted to roughing out, as they will cut much faster and be more economical in maintenance. The **multiple-lipped twist drill** is one form of chucking reamer, and is one of the best reamers for roughing out cored holes. Multiple-lipped twist drills are made with three or four cutting edges, and are usually made as shell reamers in the larger sizes and as solid reamers in the smaller sizes. The flutes are cut on a right-handed helix of such pitch as to give the cutting edges an angle of about 15° with a plane passing through the axis. A view of a three-grooved chucking reamer is shown in Fig. 24.

63. These reamers are sharpened, like twist drills, by grinding on the ends. The back part only of the lands is relieved, the front part being cylindrical and serving to guide the reamer straight. The helical grooves give keen cutting edges and insure that the reamer clears itself of chips. If made as a shell reamer, the hole must be ground to size after hardening and tempering. The outside may then be ground to size, with a taper of about .001 inch to the inch, being smallest at the back end, to prevent roughing up or binding in the hole, while the reamer is mounted on its own arbor. As reamers of this kind are intended for roughing out, they need not be ground to correct size within a fractional part of a thousandth of an inch. This fact applies to other roughing reamers as well. The hole, if the reamer is made as a shell reamer, should in general not be larger than one-half the outside diameter.

64. Square Reamers.—If a long hole is to be finished very true and very smooth, as, for instance, the bore of a rifle barrel, a type of reamer differing entirely from any shown heretofore is used. This type, which is shown in Fig. 25, is used practically to the exclusion of all other reamers for the purpose of finish reaming the bore of gun barrels. It is well adapted to similar machine-shop work.

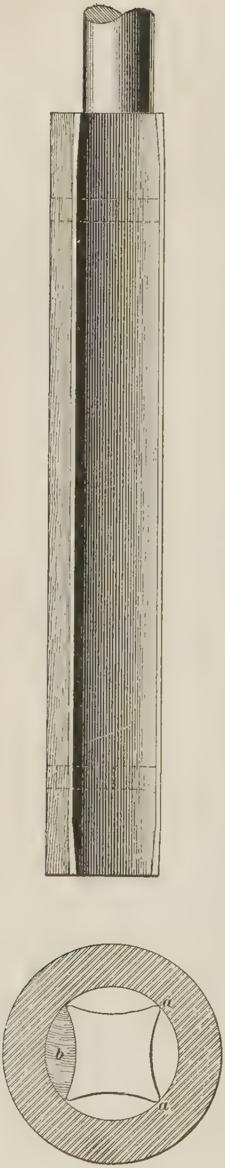


Fig. 25

The reamer is made of square tool steel. The four sides are hollowed out, as shown in the end view, in the milling machine, shaper, or planer. The reamer is then hardened and tempered, after which it is ground on the surface grinder, grinding the corners only, until it is perfectly straight and parallel. Its diameter across corners is made .003 to .004 inch smaller than the diameter of the hole to be reamed. It is then stoned carefully to give very smooth edges, using the finest grade of oilstone. The extreme ends are slightly tapered off by stoning.

65. In use, a slip of hard wood, as *b*, Fig. 25, which extends the whole length of the reamer, is inserted between one side of the reamer and the walls of the hole, causing the edges *a* to cut. After passing through the hole, a strip of tissue paper is placed between the reamer and the slip of wood, causing the reamer to take another cut. This process is repeated until the hole is the correct size. Copious lubrication is essential to good work. The slip of hard wood may be confined longitudinally by two pins, as shown. A reamer of this kind is suited only for removing minute amounts of metal. But, on the other hand, it will produce a degree of finish that cannot be excelled by any other reamer. It should be pulled through the hole in order to work best. A square reamer may be made without hollowing out the sides; it is then, however, more difficult to sharpen when worn. The length of a square reamer may be about eight times its diameter.

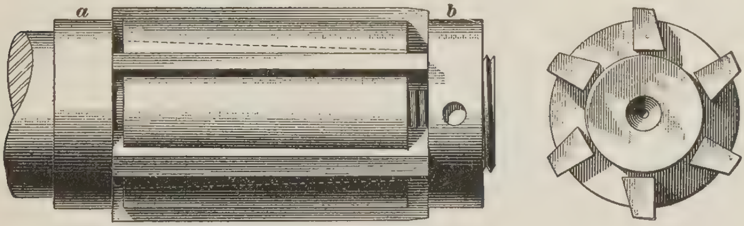


Fig. 26

66. Adjustable Reamers.—Adjustable reamers are those so arranged that the wear may be taken up and the reamer sharpened several times without losing the standard size. These reamers are purposely made so that the size to which they are set cannot be varied without machine work, the idea being to keep the user from changing the setting. In Fig. 26 is illustrated an adjustable reamer. It consists of a body containing a number of dovetailed grooves cut at an inclination to the axis. Blades that form the cutting edges are carefully fitted to these slots. These blades butt against the shoulder of the collar *a* at the back end and are firmly held against it by the locknut *b*. To show the blades clearly, the locknut has been omitted in the end view. When the reamer has worn sufficiently below size to make it unserviceable, the nut *b* is loosened, the blades are partly driven out, and the shoulder of the collar *a* is faced off sufficiently to make the reamer slightly over size when the blades are driven home again. The blades are then reground and stoned to standard size.

For a given longitudinal movement the range of expansion can be increased by making the inclination of the slots with the axis greater. The slots are usually machined on the planer or shaper, which in general is cheaper than milling them.

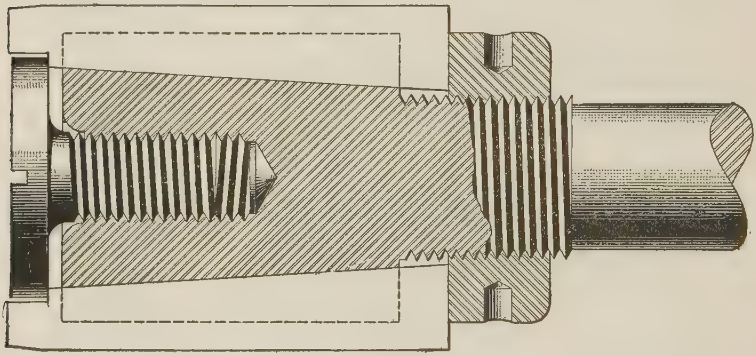


FIG. 27

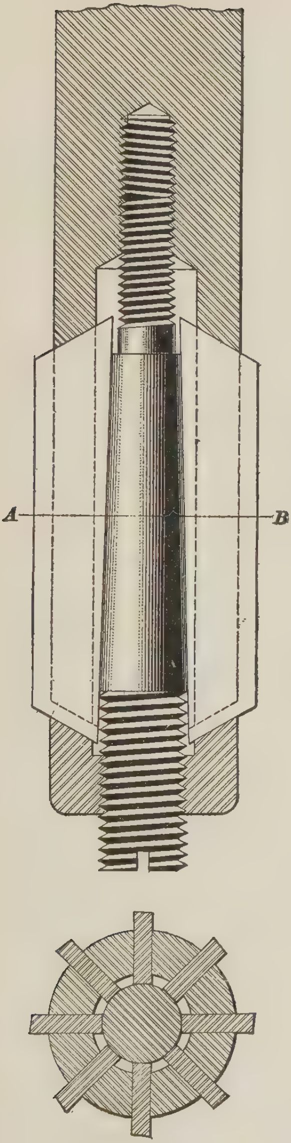
67. Expanding Reamers.—Expanding reamers are those that may be adjusted so that the diameter of the hole will vary either way from the nominal size of the reamer. They are so made that they can be adjusted by the user without machine work.

There is an infinite number of designs possible for making a reamer adjustable. Some of these are shown; these designs are not offered as finality, but as suggestions. The smaller sizes of adjustable and expanding reamers can generally be bought of the manufacturers more cheaply than they can be made; only in the larger sizes or in special reamers is there any economy in making them in the tool room.

The reamer shown in Fig. 26 can readily be converted into an expanding reamer by placing a nut in the place occupied by the collar *a*. By varying the position of the two locknuts, the blades can then be expanded or contracted slightly.

68. The design shown in Fig. 26 is suitable for holes that pass clear through the work. If the hole is blind, however, it cannot be reamed to the bottom, since the locknut projects beyond the end of the blades. The design shown in Fig. 27 may then be adopted. The dovetailed slots are here inclined the opposite way from that shown in Fig. 26. Instead of a locknut, a flat-headed screw is used at the front end, which bears against a shoulder on the under side of the blades. By means of this screw and the locknut at the back, the blades may be forced outwards or drawn inwards.

69. An inserted-blade expanding reamer of somewhat different construction is shown in Fig. 28. The blades here are flat, easily fitted, and beveled at the front and back; the slots that receive the blades are also beveled at the back end. A central tapered pin bears against the bottom of the blades; by screwing the pin in or out and screwing up the locknut,



Section on line A B.

Fig. 28

the blades are forced outwards or drawn inwards. The blades, after they are hardened and tempered, are ground flat and parallel on the sides; they must be a good fit in the slots. The inner face of the blades, which bears against the taper pin, should also be ground straight on a surface grinder. The taper pin may be hardened and drawn to a purple color; it should then be ground true. After assembling the reamer, the pin and locknut are adjusted so that the pin will be midway between its two extreme positions; its outside is then ground to standard size. The ends are relieved and chamfered off the same way as any other reamer. The locknut may be hardened, but the body of the reamer should be left soft. The body should be made of tool steel in the smaller sizes, that is, for sizes below 1½ inches. Above this size, it may be made of machinery steel. The design shown in Fig. 28 is suitable for reamers from ¾ inch up.

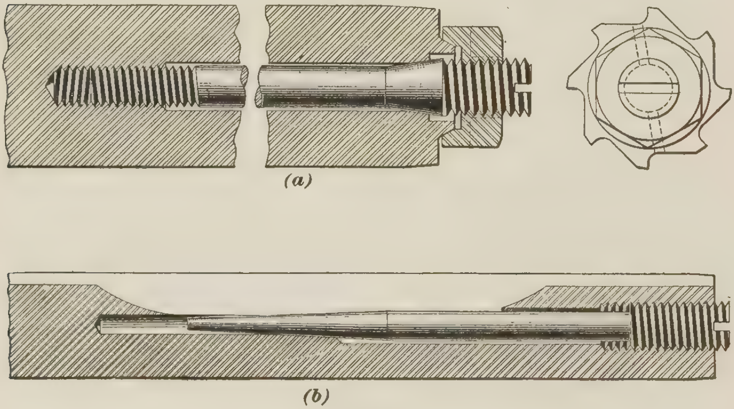


Fig. 29

70. The most common forms of expanding reamers are shown in Fig. 29. In both designs, the reamer is made at first exactly as if it were a solid reamer; an axial hole is then drilled and tapped for the adjusting screw, and, finally, the reamer is split. The reamer shown in (*a*) is split at the end, and may be expanded by screwing the taper-headed screw inwards. The setting is then locked by the locknut shown. This reamer becomes large at the end.

In the design shown in Fig. 29 (*b*), the end is left solid, but the reamer is split by sinking in a narrow milling cutter right back of the end. The slots may commence at a distance from the end equal to about one and one-half times the diameter of the reamer. The length of the slots should be about four times the diameter of the reamer. The number of parts into which the reamer is split varies with the diameter. Reamers up to $\frac{3}{8}$ inch may be split into two parts; up to $\frac{3}{4}$ inch, into three parts; and above that size, into four parts.

71. Split expanding reamers are the cheapest expanding reamers to construct; they are open to the objection, however, that expanding does not change their diameter uniformly throughout their length. Whether this objection is serious enough to prohibit their employment for a particular case must be decided upon the merits of the case.

The diameter of split expanding reamers depends on the service expected of them. If they are made expanding simply in order to be able to ream holes to a standard size, they should originally be ground and stoned to the standard diameter. If they are intended to ream holes at will slightly above or below standard size, they must be made slightly under the standard size.

72. Allowance for Grinding.—Since there is no way to prevent a reamer from warping in hardening, an allowance must be made to finish it by grinding. This allowance depends on the length and diameter of the reamer; it is least for a short and most for a long reamer. For reamers up to $\frac{3}{4}$ inch and not over 6 inches long, exclusive of shank, an allowance of .025 inch will usually prove ample, since the reamer is easily straightened sufficiently to allow it to be trued with this allowance. For every $\frac{1}{4}$ inch the reamer is above this size, the allowance may be increased .01 inch, provided the reamer is not over 8 diameters long. If longer, the allowance for grinding should be increased.

73. Front Chamfer.—Straight reamers intended to cut at their ends only, like rose reamers and chucking reamers, are to be made with a very slight taper for clearance. This taper is so slight that the part back of the cutting edges still serves as a guide. Straight reamers that have their cutting edges formed on their circumference require the front end to be slightly chamfered off in order that they may enter the hole easily.

74. Grooving Reamers.—A reamer can be grooved most rapidly in a milling machine with a suitable cutter. As a makeshift, the grooves can be planed in the lathe, shaper, or planer. This method is only recommended where no milling machine is available.

Suppose the method of spacing in which any two opposite teeth are on the same diameter has been selected. Then, the grooves are most advantageously cut in pairs; that is, after milling one groove, the one diametrically opposite is cut before passing to the adjoining one. This method is recommended because of the saving in labor accomplished by it. In the method of spacing selected, any two opposite grooves will have the same depth, and any two adjoining grooves will differ in depth. Consequently, by adopting the method of cutting the grooves in pairs, the number of times the cutter must be reset is reduced to one-half of what it would be when cutting one groove after another.

75. The irregularity of spacing is obtained by moving the index pin a different number of holes for each adjoining pair of grooves. The irregularity introduced need not be very large; one that will cause the cutting edge to diverge by 2°. to 4° from the angle corresponding to an equal division will be sufficient.

An example will show how the irregularity is introduced. It is required to cut a reamer with 8 cutting edges and the milling machine available requires 40 turns of the index pin for 1 revolution of the index-head spindle. Then, with the index pin adjusted to the circle having 20 holes, $20 \times 40 = 800$ holes must be passed over for a complete revolution of the reamer, and $800 \div 8 = 100$ holes for dividing into eight equal divisions. As a movement of 800 holes causes the work to revolve through 360°, the angle through which it is revolved by a movement of 1 hole is $\frac{360}{800}$ = say $\frac{1}{2}^\circ$, or .5°

76. If an irregularity of 2° must be introduced, a movement of $\frac{2}{.5} = 4$ holes is needed. Then, by a judicious selection, the number of holes to be passed over for each division is arranged. For instance, 95, 99, 105, and 101 holes may be used successively for adjoining grooves, and, after cutting each groove, 20 turns may be given to pass to the opposite one. With this number, the greatest difference between adjoining grooves is that corresponding to $101-95=6$ holes, which is about $6 \times \frac{1}{2} = 3°$. If the number of holes selected for successive grooves had been 98, 102, 106, and 94, the greatest difference between adjoining holes would have been that corresponding to $106-94=12$ holes; or $12 \times \frac{1}{2} = 6°$. In selecting the holes, it must be remembered that the sum of the holes must be equal to one-half the number of holes required for a whole revolution of the reamer. Consequently, the number of holes required for the last groove is equal to the difference between the sum of the preceding ones and the number of holes required for one-half of a revolution of the work.

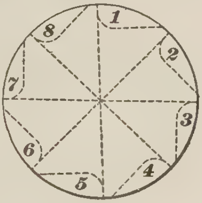


FIG. 30

77. The moves that are to be made successively in order to obtain the spacing are as follows for the particular division and spacing selected: To cut the first groove in Fig. 30, none; to cut the fifth groove, 20 complete turns of the index pin; to cut the fourth groove, 95 holes, or 4 turns and 15 holes; to cut the eighth groove, 20 complete turns; to cut the seventh groove, 99 holes, or 4 turns and 19 holes; to cut the third groove, 20 complete turns; to cut the second groove, 105 holes, or 5 turns and 5 holes; and to cut the sixth groove, 20 complete turns. A movement of 101 holes, or 5 turns and 1 hole, will bring the cutter to the fifth groove again, and 20 complete turns to the first groove.

When making a solid reamer, it is necessary to go around twice, sinking the cutter in deep enough the first time to distinctly mark the position of the cutting edge. When back to the first groove, the cutter may be sunk deep enough to give the proper width of land, which can be determined readily if the position of the cutting edge of the adjoining groove is known. Then, after cutting grooves *1* and *5*, the cutter must be reset to the proper depth for grooves *4* and *8*, *7* and *3*, and, finally, *2* and *6*. If the grooves are helical, the spacing is obtained in just the same manner.

78. The 20-hole circle need not necessarily be used for an 8-grooved reamer, nor the number of holes passed over for each division be just as given in the preceding discussion. The numbers of holes and the 20-hole circle have been arbitrarily selected to illustrate the principle involved.

79. Temper of Reamers.—The cutting edges of a reamer may be tempered to suit the service to be performed. When the reamer is to be used for roughing, such as to remove a relatively large amount of metal in one operation, the cutting edges should be soft and tough enough to stand the strain of cutting; when a reamer is intended for finishing and accurate sizing of holes, where it has to remove only a very small amount of metal, it should be made quite hard. A roughing reamer of carbon or semi-high-speed steel, after being hardened so that a file will not touch it, may be drawn to a full straw color, while a finishing reamer may be left a pale straw color. If the finishing reamer is intended for very light service, and if the wear of the reamer must be reduced to its lowest limit in order to make a large number of holes uniform in size, the reamer may be left as hard as possible.

If the reamer blades are made of high-speed steel, they are heat-treated to give them their cutting properties.

80. Grinding Reamers.—The reamer is first ground to run true, revolving it between the grinding machine centers. It may be ground, according to its size, to within .001 to .002 inch of the finished size. The clearance is then ground with the grinding wheel so set that its periphery will clear the front edge of the tooth succeeding the one being ground. The reamer is kept from rotating by a finger so adjusted that the correct clearance will be ground. The height of the finger is so adjusted that the cutting edge is *below* the perpendicular line from the center of the grinding wheel to the center line of the reamer. The farther the cutting edge is placed below this perpendicular line, the greater the clearance produced by the wheel; conversely, the nearer to this perpendicular line, the less the clearance. From this, it is seen that varying amounts of clearance can be obtained with the same wheel and on the same reamer by varying the height of the finger.

81. In grinding the clearance, as large a grinding wheel as the machine will handle should be used, since the larger the wheel, the less concave the clearance will be. A small wheel will grind the clearance so hollow that the cutting edge will be deprived of support. The metal must be removed by a succession of light cuts, going successively around the reamer. It is of the utmost importance that the temper of the cutting edge should be preserved; a heavy cut taken with a dry grinding wheel is almost certain to anneal the cutting edge, thus rendering the reamer worthless. The clearance must not be ground up to the cutting edge; according to the size of the reamer, it may be ground to within from .01 to .02 inch of the edge. No matter how carefully a reamer is ground, the grinding wheel will leave minute ridges on the reamer that will be transferred to the hole reamed. The reamer is then brought to a sharp edge and to correct size by oilstoning.

82. Oilstoning Reamers.—One way to bring the reamer teeth to a sharp, smooth edge is to rub them with an oilstone by hand. Owing to the difficulty of obtaining straight edges and the liability of leaving a spot or two on the lands higher than the cutting edges, considerable experience and much skill are required to finish a reamer for accurate work by this method.

Another way to bring the reamer teeth to a sharp, smooth edge is to oilstone them on the grinding machine, replacing the grinding wheel with an oilstone. To avoid too great a clearance angle, the supporting finger is raised slightly before smoothing the edges with the oilstone wheel. If this was not done, the fine, knife-edged teeth produced would wear off rapidly, causing the reamer to become undersize after a few holes had been reamed.

83. Remaking of Worn Solid Reamers.—In spite of the most careful use, reamers will wear and hence will ream holes smaller than the standard size for which they were made. No rule can be laid down to decide the question of when a reamer has worn enough to become unserviceable. When a finishing reamer has worn down too much, it may be sharpened. As sharpening reduces the size of the reamer, it is then suitable for a roughing reamer only. Sometimes the reamer is annealed and remilled to a smaller size, and then hardened and ground.

84. Enlarging Worn Shell Reamers.—When shell reamers become worn below size, they may often be restored by the method described in the preceding article. However, since it is not possible to tell whether the hole will enlarge or become smaller, there is no certainty that it can be used on the same arbor afterwards. If the hole is made tapering, it can usually be done; if the hole is straight, this is rather uncertain.

85. Helical Cutting Edges.—The purpose of helical cutting edges is to prevent a reamer from drawing into the work. A left-hand helix should be chosen for a straight reamer that is to turn right-handed. The helix should be such that the cutting edges will make an angle of about 15° with a plane passing through the axis of the reamer. Right-handed helical cutting edges are of advantage for taper reamers having considerable taper and for formed reamers differing considerably in their various diameters, as it will assist them to cut. Finishing taper reamers and finishing formed reamers may have their cutting edges left-handed, if made helical. Some toolmakers claim that if thus formed, owing to the shaving cut taken, they will produce a smoother and truer hole than can be obtained otherwise.

The advantages of helical cutting edges for straight reamers are somewhat doubtful, at least for general work; many toolmakers believe that the extra expense involved in making them is not justified by the results, claiming that, with reasonable care, just as true and smooth a straight hole can be obtained with a reamer having its cutting edges straight. Helical cutting edges for straight reamers are recommended when holes are to be reamed that are pierced crosswise by openings. All remarks previously made in regard to spacing, number, and clearance of cutting edges apply to helical cutting edges as well.

TAPER REAMERS

86. Example of Stepped Reamer.—If intended for finishing, taper reamers are made on the same principles that govern the construction of straight reamers. Roughing taper reamers are often made in the same manner, but with right-handed helical cutting edges. If the taper of the reamer is at all large, the roughing reamer may be made as shown in Fig. 31. This construction is an extension of the principle on which a counterbore is based; in fact, each step in conjunction with the adjoining one forms a counterbore. All cutting is done at the forward end of the steps; the cutting edges, as *a*, are formed by backing off with a file. The cylindrical surfaces of each step are given no clearance, as they serve the purpose of guiding the succeeding cutting edges. The reamer may be given four cutting edges, which may be cut with a milling cutter suitable for a tap of the same size.

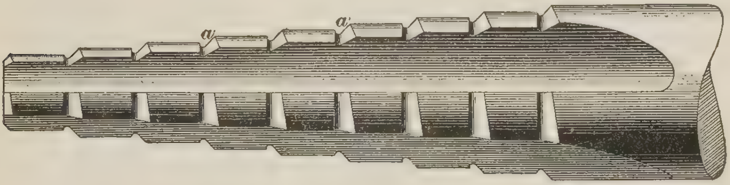


FIG. 31

Stepped reamers may also be made of suitable form to rough out holes that are to be finished with formed reamers. The number of steps that are to be used for a stepped reamer must be decided separately for each case, bearing in mind that the greater the number of steps for a given length of reamer, the less work will be left for the finishing reamer.

87. If a number of taper reamers of the same size and taper are required, and especially if they are constantly in use and must frequently be reground or replaced, a gauge to which they can be fitted becomes necessary. This gauge may be a hole of proper size and taper in a cylindrical piece of tool steel that has been hardened and ground.

88. Grooving Taper Reamers.—If the reamer is to be used for brass or cast iron, the flutes may be made straight, as shown in Fig. 31; if it is to be used for roughing wrought iron and steel, the flutes may be helical, using a right-hand helix of such a pitch that it will make an angle of about 15° with a plane passing through the axis. The reamer being intended to turn right-handed, the cutting of right-handed helical flutes has the effect of giving keen cutting edges, which will make the reamer work easily; at the same time, the chips are crowded back toward the shank. When turning up a stepped reamer, it is advisable to neck it down a little with a round-nosed tool at the end of each step. When grinding, these grooves allow the grinding wheel to pass entirely over the surfaces and make it easier to sharpen the cutting edges. The cutting edges are backed off by filing before hardening; when grinding cylindrically, the cutting edges of each groove are trued, removing as little metal as possible. These grooves are again brought to a sharp edge by careful hand grinding on a beveled wheel, or by oilstoning.

FORMED REAMERS

89. When holes that are neither straight nor tapering are to be finished by reaming, so-called formed reamers must be used. Some shapes of formed reamers can be readily ground in the ordinary grinding machine; others, again, require special apparatus for their production. Formed reamers in general are avoided when possible, as they are very expensive in first cost and exceedingly difficult to duplicate if a great degree of accuracy is required. There are some jobs, however, that cannot be done without them; in that case, the toolmaker must use his ingenuity as to the best way of making them of the correct size and shape.

TOOLMAKING

(PART 3)

CUTTING TOOLS

COUNTERBORES

1. The selection of a counterbore depends on the nature of the metal to be worked, the number and the range in the size of holes to be counterbored, and the distribution of metal around the hole. Counterbores may be of the solid or the built-up construction.

SOLID COUNTERBORES

2. Two-Lipped Flat Counterbore.—When a counterbore is to be used for a relatively small number of holes and is to be thrown away after serving its purpose, it is advisable to adopt a cheap construction in order to reduce the first cost to the lowest limit. Probably the cheapest counterbore that can be made is the two-lipped flat counterbore with a solid pilot, which is shown in Fig. 1. This counterbore can be forged very near to shape and needs but little machine work and filing to make it serviceable. After being forged, the work is centered, the shank turned to the required size, and the pilot turned nearly to size, being finished with a fine file. The cutting end is now turned to the correct size and the cutting edges are faced and filed for clearance.

If the counterbore is to be used for wrought iron or steel, a keen cutting edge may be given by filing as shown at *a*, Fig. 1, in dotted lines. For cast iron and brass, it is better to leave

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the cutting edges without any front rake. A slight relief may be given to the faces *b* to prevent them from binding in case the countersinking is to be carried to an appreciable depth. If the counterbore is intended only for squaring up the face around a hole, no relief need be given. Only the cutting edges need be hardened; if of carbon or semi-high-speed steel, they may be drawn to a straw color. The process of hardening leaves the pilot hard; some toolmakers draw the end of the pilot to a blue color by inserting it into red-hot lead to prevent its breaking off. Since the pilot is most liable to break off close to the cutting edges, however, and since it cannot be drawn to a spring temper clear up to the edges without partly softening them, many toolmakers believe that it is a waste of time to draw the temper of the pilot.

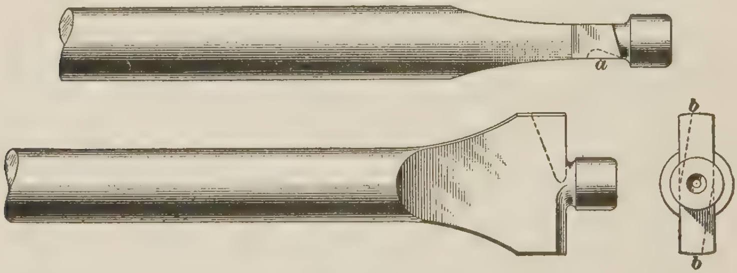


FIG. 1

3. Four-Lipped Counterbore.—When a hole is drilled close to a projection, and when it is required that the counterbore should cut part of the projection away, it is better to use a counterbore with four cutting edges. It may be turned down from bar tool steel and have its cutting edges formed by cutting grooves with a 60° milling-machine cutter. The grooves may be cut on a right-handed helix, making an angle of about 15° with a plane passing through the axis of the counterbore if it is intended for wrought iron and steel. For brass and cast iron, the grooves may be straight. The cutting edges are backed off and the lands are given clearance by filing.

4. Objections to Solid Counterbores.—While low in first cost, solid counterbores are open to two serious objections:

In the first place, they are difficult to sharpen; in the second place, they are limited in their range to holes as large as the pilot or larger. They can be adapted to larger holes by forcing a bushing over the pilot. As it is rather difficult to remove the bushing, this method of making a counterbore adapted to several sizes of holes can only be considered as a makeshift, especially as the difficulty of properly sharpening it is retained.

BUILT-UP COUNTERBORES

5. **Inserted-Pilot Counterbore.**—The counterbore shown in section in Fig. 2 overcomes the objections raised against the solid counterbore. It is slightly more expensive to make, but will serve for a greater variation in size of hole than any other. In addition, it can be sharpened very easily. As shown in the figure, it has a central hole bored to receive the shank of the pilot, which is held in place by the setscrew. After turning the outside, the central hole may be bored true, running the large end of the counterbore in the steady rest. The grooves may then be cut in the milling machine, the work being held between the centers or in the chuck, as is most convenient. A 60° milling cutter may be used if four cutting edges are required. For wrought iron and steel, the grooves may be cut along a right-handed helix; for brass and cast iron, they may be straight. After hardening and tempering, the hole should be lapped out; pilots of the desired sizes may then be turned and fitted to the counterbore. These pilots may be hardened at the end and drawn to a straw color. Unless the counterbore is used for exceptionally fine work, there is little need of grinding the pilot to run true. As they are to be hardened at the extreme end only, there is little likelihood of their springing sufficiently to interfere with the working.

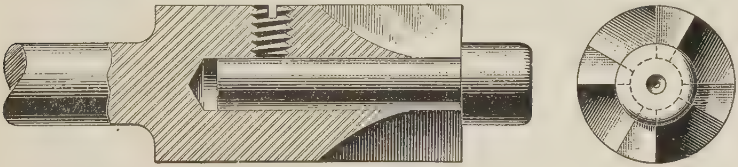


FIG. 2

The shank of the pilot should be a good sliding fit, so that it may be easily removed when the setscrew is loosened. The counterbore can readily be sharpened by grinding on the end after the pilot is removed.

6. Inserted-Cutter Counterbores.—When but very few holes of a special size are to be counterbored and there is little likelihood of the counterbore ever being wanted again, the simple form shown in Fig. 3 may be adopted. Its chief recommendation is its cheapness. The objectionable feature is that it can take but a relatively light cut, which requires careful feeding to prevent breakage of the cutter. The counterbore consists of a bar that fits the hole to be counterbored and a cutter driven into a circular hole drilled clear through the bar. After the bar is turned to size, the hole for the cutter is drilled and reamed; and a piece of annealed carbon steel or high-speed steel of sufficient length is filed flat on one side, driven home in the hole and held by the setscrew. This piece of steel is then turned to the correct diameter and faced on the front side. It is next driven out of the bar and filed to a cutting edge, as shown, giving front rake for wrought iron or steel. The cutter is now hardened all over, its temper is drawn to a light straw color, it is driven home again, and held in place by a setscrew.

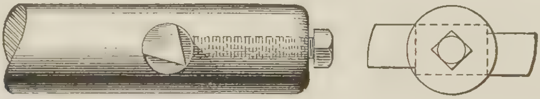


FIG. 3

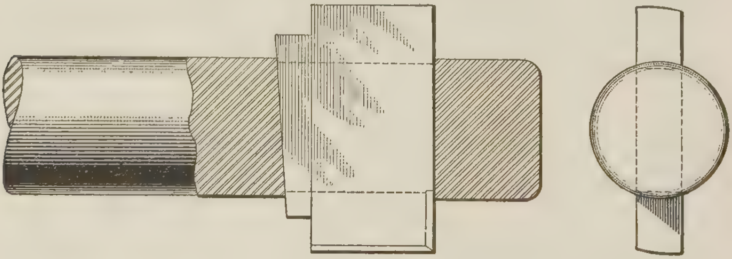


FIG. 4

7. For large work, a counterbore may be made as shown in Fig. 4. The bar is slotted and a flat cutter is closely fitted to it; the cutter, which is readily sharpened, is confined by a key, as shown. A moderate range of variation in the diameter of the counterbored hole is obtained by setting the cutter out of center. The end of the bar may be hardened and its temper drawn to a dark straw color; or it may be left soft and turned to receive a hardened bushing that is a good snug fit and kept from turning by a pin; or, if the pilot hole must be kept smooth, the bushing may be fitted to the hole and the hardened end of the bar rotate in it.

HOLLOW MILLS

SOLID HOLLOW MILLS

8. Hollow mills are chiefly used for screw-machine and turret-lathe work for roughing down and finishing stock preparatory to threading. When intended for finishing, they are usually made adjustable. For roughing out, solid mills are preferred, since in general they are not as springy as adjustable mills. Hollow mills may be made in a great variety of forms. For small work, the most common form is the solid mill shown in Fig. 5. This is commonly made with four cutting edges formed by milling with a side milling cutter of about double the outside diameter of the mill. In order that the mill may work easily, the inside of the cutting edges must be relieved lengthwise, as shown. The rear of the mill is to be bored larger in

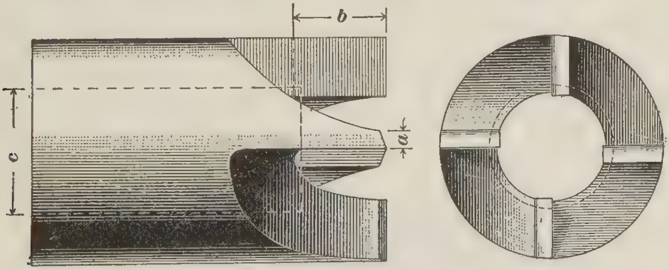


FIG. 5

diameter than the cutting end. This process allows it to clear on long cuts and at the same time makes it easier to file the clearance.

9. In making the mill, if the cutting edges are milled out before giving the clearance inside, the clearance can be filed more rapidly, since there is then but a relatively small quantity of metal to be removed. The milling cutter is set by trial until it makes *a*, Fig. 5, about one-sixth and *b* about eight-tenths of the inside diameter. The back of the mill *c* may be bored about one and one-fifth times the diameter at the front end. The faces on which the cutting edges are located are usually spaced equidistant and lie in planes passing through the axis. The mill is hardened as far back as the teeth extend, and, being made of carbon or semi-high-speed steel, is drawn to a straw color from the back by setting it on a red-hot piece of iron. All sharpening is done by grinding on the end.

An adjustable hollow mill may be constructed in the same manner as the adjustable spring die shown in *Toolmaking*, Part 2. A clamp collar is used to adjust it.

INSERTED-BLADE HOLLOW MILLS

10. For large work, hollow mills may be made with inserted blades, constructing them if desired non-adjustable in the same manner as the solid die shown in *Toolmaking*, Part 2. If desired adjustable, a design similar to that of the adjustable die may be adopted.

A very good design of a hollow mill with removable blades and adjustable for sizes within narrow limits, is shown in Figs. 6 and 7. Fig. 6 shows the mill taken apart; Fig. 7 shows it assembled.

The mill consists essentially of a body *a*, Fig. 6, in which a number of slots, as *b*, are cut at an inclination to the axis. These slots receive the cutters *c*, which are a loose fit in them. The cutters are rectangular in cross-section; their rear end butts against the adjusting nut *d*. They are held in place and surrounded by a tapering collar *e*, which is pushed home by a locknut *g* located at the front end. The inside of the collar *e* is bored out sufficiently large to clear the body *a* and to fit the outside of the cutters, which extend slightly above the tapered surface of *a*. Clearance spaces for the reception of the chips are cut between the slots, as shown at *f*. These clearance spaces communicate with the outside by an opening cut through the body and a corresponding opening in the collar.

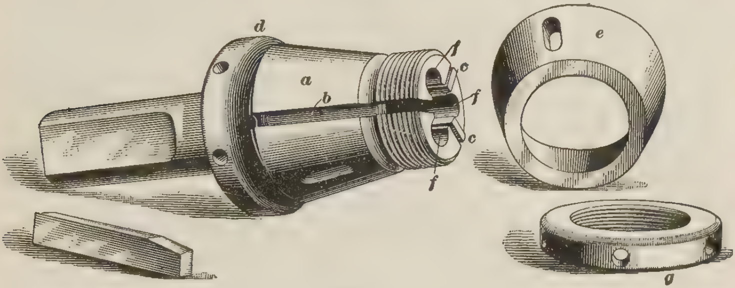


Fig. 6

11. To set the mill to a smaller size, the locknut *g*, Fig. 6, is loosened in order to loosen the cutters. These are then pushed forwards and consequently closed in by turning the adjusting nut *d* forwards. Tightening the locknut forces the taper collar over the cutters and thus locks them. To set the mill to a larger diameter, the cutters are loosened by unscrewing the locknut; the nut *d* is then turned back and the cutters pushed against it by hand. They are locked again by screwing the locknut home.

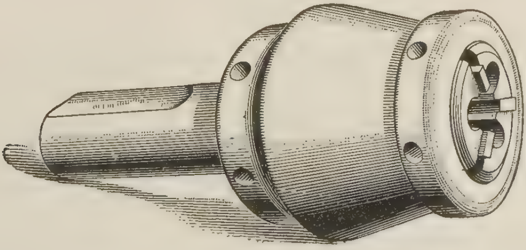


Fig. 7

A hollow mill constructed in accordance with this design is rather expensive as far as first cost is concerned. It is very economical in its maintenance, however, since new cutters can be made for it at a very slight cost. By making the cutters of suitable shape, the mill can be adapted to a limited range of sizes.

12. Making Hollow-Mill Cutters.—When making the mill it is advisable to cut the slots so that their bottoms will be at the same distance from the axis, in order that all the cutters may be alike. It is preferable to mill the cutters to the exact shape required, although they are occasionally filed to shape in a filing jig. After the first set of cutters has been made, a filing jig may be constructed, in which spare cutters can be filed alike in height, length, and shape of cutting edge.

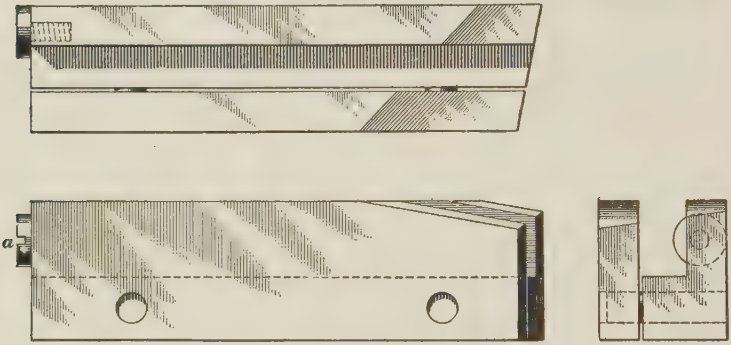


FIG. 8

A simple filing jig for this purpose is shown in Fig. 8. It consists of two parts of tool steel doweled together, the work being placed between them and clamped in position in an ordinary vise. One of the cutters out of the first set made serves as a model in making the jig; it is placed between the two parts of the jig, butting its rear end against the stop *a*, and clamped in a vise. The jig is then worked down to the height of the cutter and is beveled to suit it, the hardened cutter serving as a guide. The jig is now hardened and used to duplicate the cutters. Before the jig can be used, the cutters must be cut down to the correct width for the slots in the mill body, and the slots should be exactly alike to allow the cutters to interchange.

HOLLOW MILL FOR ANNULAR MILLING

13. Hollow mills can be used with advantage on some classes of work for milling the outside of a cylindrical projection central with a hole passing through it, provided great accuracy is not required. The mill is then made with a central guide pin, as shown in Fig. 9, to fit the hole in the work.

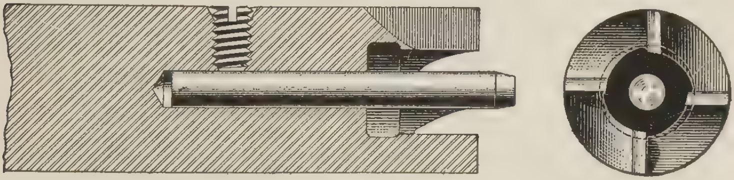


FIG. 9

This pin should be hardened at the end and drawn to a spring temper. It should be held by means of a setscrew to allow ready removal when the mill is to be ground. To aid the filing of the inside clearance, the rear end of the mill should be bored out somewhat larger than the front end.

MILLING CUTTERS

SOLID MILLING CUTTERS

14. Milling cutters up to 6 inches in diameter are usually made solid and above that size they are made with inserted teeth. The number of cutting edges for solid milling cutters intended for general work may be as given in Table I, which conforms very closely to average practice.

15. The cutting edges are generally made with a radial face, as indicated by the dotted lines in Fig. 10; the spaces on the circumference may be cut with a cutter that will produce an angle *a* between the face and the back of the tooth of about 50° for carbon steel, and 45° for high-speed steel cutters. This angle gives an ample depth to the clearance spaces and at the same time gives well-supported cutting edges. The milling cutter used for forming the teeth is run in deep enough to leave the lands of the proper width, according to the size of the cutter that is being made. If teeth are cut on the sides or ends of the cutter, as shown in Fig. 10, the spaces may be cut with a milling cutter that will produce an angle with the side or end cutting face of 60° to 70° for carbon-steel side-milling and end cutters and high-speed-steel end mills, and of 84° for high-speed-steel side cutters. When milling the teeth on the sides, the index head is inclined a little from the 90° mark in order that the cutter may make the lands of equal width. The amount that the index head is to be inclined depends on such variable conditions that computation of it is a difficult problem; in practice, it is most rapidly found by an actual trial.

TABLE I

CUTTING EDGES FOR MILLING CUTTERS

Diameter of Cutter Inches	Cutting Edges Carbon Steel	High-Speed Steel
$\frac{1}{2}$	6	
$\frac{3}{4}$	8	
1	12	4
$1\frac{1}{4}$	14	6
$1\frac{1}{2}$	16	6
2	18	8
$2\frac{1}{2}$	21	8
3	24	8
$3\frac{1}{2}$	26	9
4	28	10
5	30	12
6	32	14

16. Tempering Cutters.—After cutting the teeth, all burrs are removed by filing and the cutter is hardened. If the cutter is of carbon or semi-high-speed steel, the temper is drawn to a straw color; if of high-speed steel, the cutter is given the proper heat treatment. A good way to draw the temper of cutters made of carbon or semi-high-speed steel is to insert a red-hot piece of iron in the hole. A cutter whose temper is thus drawn will be softest at the inside. Since the diameter of the hole is very likely to change in hardening, it is considered good practice to make it slightly smaller, say, .004 inch per inch diameter of the hole, and finish by grinding. To reduce the time required for grinding the hole, it may be recessed, as shown in the sectional view of Fig. 10. The sides of the boss are ground square with the hole, so as to fit the clamping collars.

17. Grinding Milling Cutters.—The teeth are sharpened on a cutter grinder, using the finger of the grinder as a means for obtaining the proper cutting clearance. The teeth may be given a clearance of about 3°; that is, the angle between the face and the top of the teeth may be about 87°. If this degree of clearance is given, the teeth will cut freely and the cutter will last well. If more clearance is given, the cutting edges will dull quite rapidly. For grinding the teeth on the side of a milling cutter, a small grinding wheel is used in order to get proper cutting clearance without touching the adjoining cutting edge. The side teeth of the cutter may be ground by using a cup, or saucer, wheel of any convenient size, the cutter

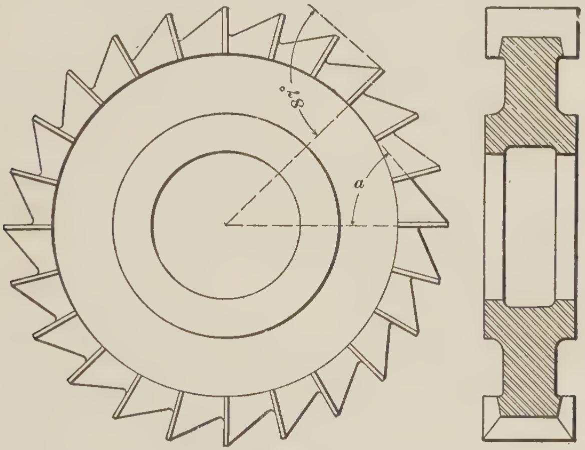


Fig. 10

being set at an angle to the wheel. The method of grinding milling cutters resembles closely that employed in grinding reamers; the only difference is that the cutting edges, as a general rule, are finished entirely by grinding, no oilstoning being done on them.

To get the best work out of a milling cutter, a cutter grinder should be used for sharpening it. A cutter cannot be ground by hand so that it will be round. Milling cutters that cut only on their ends when used for grooving may be advantageously ground so as to be slightly smaller at the rear, say about .01 inch per inch of length. When grinding cutters of carbon or semi-high-speed steel, only very fine cuts must be taken, since otherwise the temper will be drawn from the extreme cutting edges, which spoils the cutter. Heavier cuts may be taken when grinding cutters made of self-hardening or high-speed steel. The grinding of a cutter cannot be hurried without danger to the cutting edges.

18. **Helical Cutting Edges.**—The teeth of a helical or spiral milling cutter are made with a slope of about 20°. It makes no particular difference whether the helix is right-handed or left-handed when the cutter is intended for a machine in which the cutter arbor is supported at the end. However, when used for a machine in which the end of the arbor is free, the helix should be such that the end thrust due to the action of the cutting edges will tend to force the arbor home; that is, if the cutter is right-handed, the helix should be left-handed; if the cutter is left-handed, the helix should be right-handed. The terms "right-handed" and "left-handed," when applied to milling cutters, are defined as follows: Standing in front of a milling machine with a horizontal spindle, and looking toward the spindle, if the milling cutter revolves in the direction of the hands of a watch, it is a *left-handed cutter;* if it revolves in a direction opposite to that of the hands of a watch, it is a *right-handed cutter;* A right-handed helix, however, is one that, in advancing, turns in the direction of the hands of a watch. A left-handed helix turns in a direction opposite to that of the hands of a watch.

19. Nicked Teeth.—For heavy milling, spiral milling cutters with **nicked teeth,** Fig. 11, are an advantage, since by breaking up the chips they enable a heavier cut to be taken than is possible with an ordinary cutter. A satisfactory way of nicking them is to gear an engine lathe to cut a thread having a pitch a little less than the distance between two teeth of the cutter, and to gear the relieving attachment to back off each nick. Using a round-nosed tool, nicks having a width equal to about one-fourth the pitch of the thread are now cut. The nicks may be roughed out, without relieving, before the clearance spaces are milled, and relieved after milling. Instead of backing off the nicks with the use of the relieving attachment, they may be backed off by hand filing. To work to best advantage, it is essential that they be backed off.

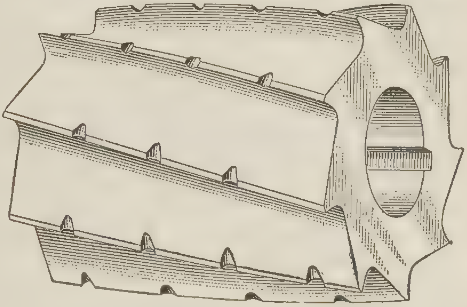


FIG. 11

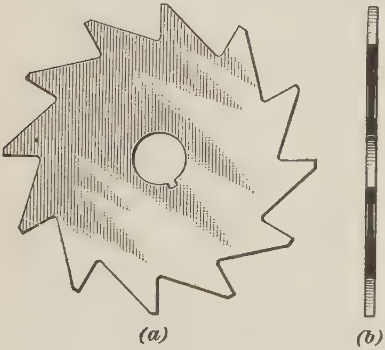


FIG. 12

20. Making Metal-Slitting Saws.—Let it be required to make a $6'' \times \frac{3}{16}''$ high-speed-steel, metal-slitting saw, Fig. 12 (*a*), to be used on a 1-inch milling arbor. In Fig. 12 (*b*) is shown a section of the cutter, exaggerated in width. The thickness of the hub is equal to the thickness of the cutting edge of the teeth. A piece of carefully annealed high-speed steel of about $6\frac{1}{2}$ inches in diameter and from $\frac{1}{4}$ to $\frac{3}{8}$ inch in thickness is chucked in the lathe. The work is then spotted and drilled, using about a $\frac{1}{2}$-inch drill. The compound rest is now set up to turn the sides of the cutter slightly thinner next the hole than at the outer surface and the sides of the cutter are trued up by using a side tool. So much stock is removed at this operation that just enough to true up will be left on the opposite face. The hole is now bored to within .002 or .003 inch of the finished size; the work is then removed from the chuck without disturbing the setting of the compound rest. After removing the chuck from the lathe, the face plate is put on the lathe and the stock is clamped to it, the clamps being located very close to the outer edge of the work. The rough side of the stock is next faced, making the thickness of the cutter at the outer circumference $\frac{3}{16}$ inch plus about .010 inch, and the cutter is then turned out to a diameter of 6 inches.

21. The work is next clamped in the shaper or slotter vise and the keyway is cut to size, using a splining tool whose width has been ground to equal the width of the keyway to be cut. A convenient way to set the tool is to measure the distance from each side of the hole to the side of the tool, using a small scale for this purpose. When the distances measured are equal, the tool is set central. The depth of the keyway may be measured by the use of a 1-inch scale or the end graduations on a 6-inch scale.

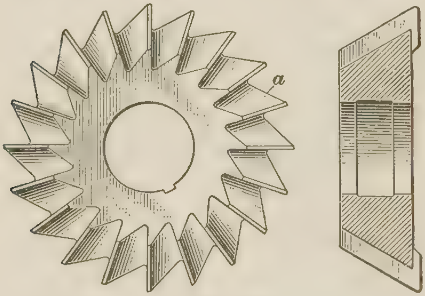


Fig. 13

22. The work is now taken to the milling machine and, in accordance with Arts. **14** and **15,** the machine is set up to cut twelve teeth with a cutter, Fig. 13, which will produce an angle of about 45° between the face and the back of the tooth. If the toolmaker is working from a drawing made by the tool designer, the desired angle will probably be given. If not, a cutter is selected which, in the judgment of the toolmaker, will give the proper angle and a trial cut is made. This trial cut is not made the full depth; and after cutting two consecutive teeth, if the angle produced is not that desired, a cutter of different angle is selected. Experienced toolmakers will generally select the proper cutter at the first trial; it will seldom be necessary to try more than two cutters before the proper one is obtained. In setting up the cutter, care must be taken to line up the cutting edges *a* with the center line of the milling arbor. A satisfactory way to do this is to place one end of a 6-inch straightedge or rule on the edges of two opposite teeth, and adjust the machine till the other end of the straightedge lines up with the point of the tailstock center.

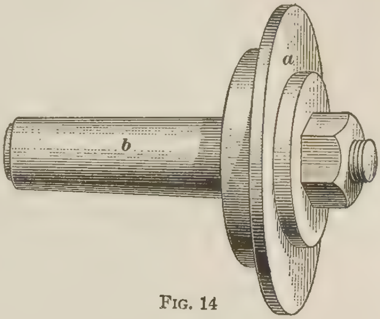


FIG. 14

23. After setting up the cutter, the work *a*, Fig. 14, is rigidly clamped on a milling arbor *b*, which is held in the index head, and the teeth are milled to nearly a sharp point. The diameter and width are now marked on the cutter, which is taken to the hardening room and heat treated. After heat treating, the cutter is clamped centrally to the face plate of the grinding machine and the hole is ground to size, using the internal grinding attachment.

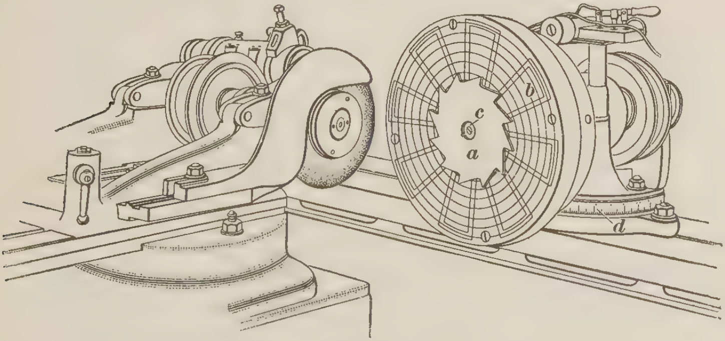


FIG. 15

The face plate is then removed and the magnetic chuck is secured to the headstock of the grinding machine, as shown in Fig. 15. The cutter *a* is located centrally on the chuck face *b* by the 1-inch washer *c*, which runs true and is not as thick as the cutter, and the headstock is set by the use of the graduations *d*, so that the cutter will be ground thinner at the center than at the outer edge to provide the proper clearance. After truing up one side of the cutter, it is reversed and the other side is ground so that the thickness of the cutting edges will be $\frac{3}{16}$ inch, the setting of the headstock remaining unchanged. The cutting edges are now ground on a cutter grinder and the cutter is ready for use.

24. Making a Special Cutter.—Let it be required to make the cutter shown in Fig. 16 out of carbon steel. This cutter is to have teeth cut on the surfaces *a*, *b*, and *c*. A piece of $\frac{9}{16}$- or $\frac{5}{8}$-inch drill rod is held in a spring collet in a bench lathe, if available; if not, a 10- or 12-inch engine lathe is employed. Using the taper attachment or compound rest, the shank is now turned tapering to fit the Brown & Sharpe No. 4 standard taper gauge, or, if no gauge is available, the socket in which the cutters are to be used. The work is now cut from the bar, using a cutting-off tool. In turning the taper, the cutting tool must be set exactly on center; otherwise, an irregularly shaped shank will be produced. A good way to test the taper turned is to make a mark with chalk, or other marking material, lengthwise on the shank, fit the shank snugly in the gauge, and rotate the work in it. When the shank is removed from the gauge, if the marking material has been rubbed off uniformly the entire length, the tapers of the shank and gauge correspond. If a number of cutters are to be made, all the shanks are turned at this setting of the lathe.

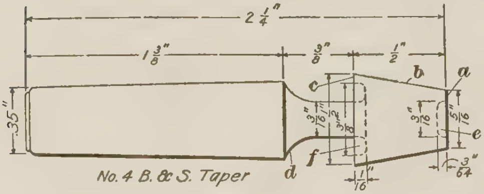


Fig. 16

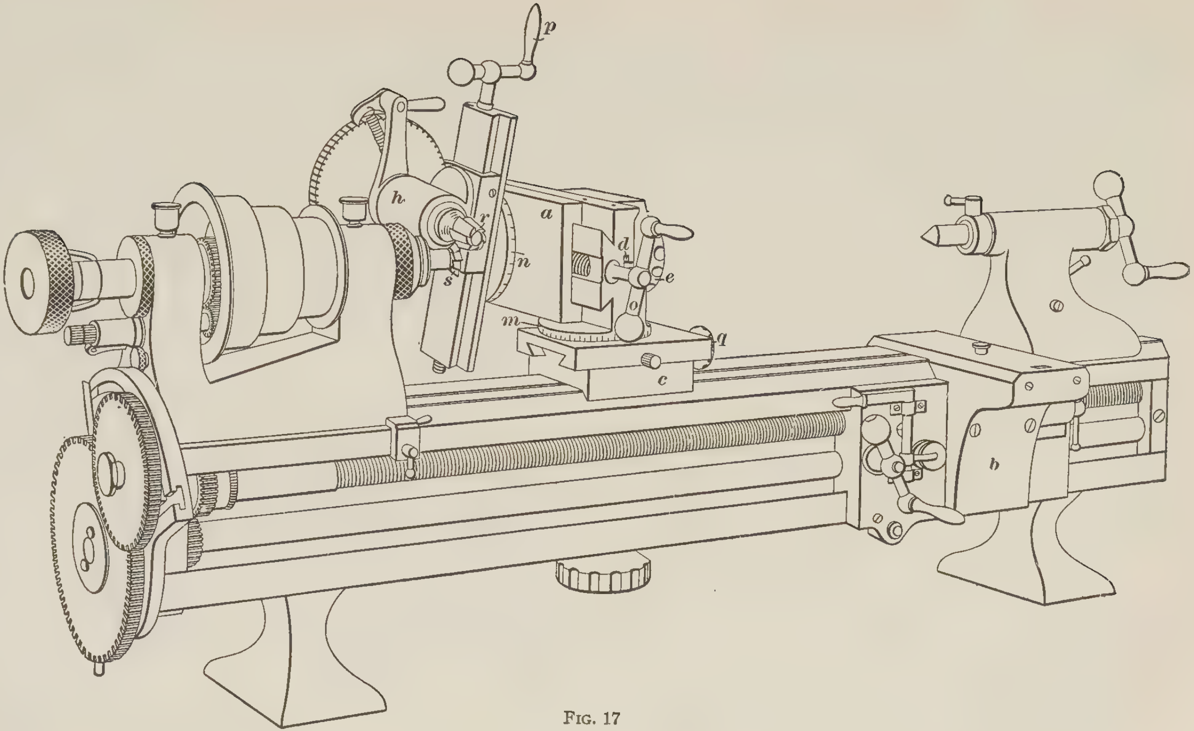
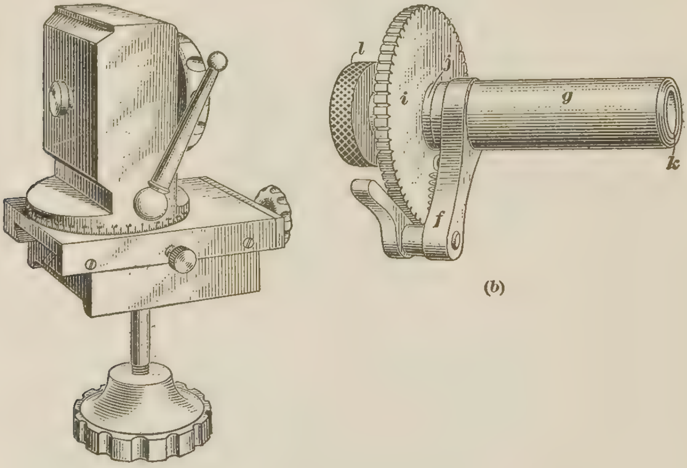


FIG. 17

25. A No. 4 Brown & Sharpe tapered socket is now fitted to the spindle of the lathe, the work is inserted in the socket, and the surfaces *a*, *b*, *c*, *d*, Fig. 16, are roughed nearly to size. The end *a* is now faced off to size; the tapered surface *b* is turned, using the compound rest, to fit a special gauge. This surface is not turned to size, enough stock being left to true up when grinding. If turned so that it will lack $\frac{1}{16}$ inch lengthwise of fitting the gauge, the surface will probably true up when ground. The end of the cutter is now undercut at *e*, care being taken to leave no sharp corners, as they are apt to cause cracking when hardening. The end *c* is now faced to size, the surface *d* is finished, and the cutter is undercut at *f*, sharp corners being avoided. The work is now ready for milling.

26. The milling attachment is now applied to the bench lathe and the teeth are milled. In Fig. 17 is shown the milling attachment and the work set up in the lathe. The slide rest *a* is removed from the carriage *b* and fastened to the revolvable tailstock *c* by a screw, which fits in the **T** slot *d* and the nut *e*. The revolvable tailstock *c* is shown separately in Fig. 18 (*a*) and the indexing mechanism and socket are shown in (*b*). The arm *f* and sleeve *g*, in (*b*), are rigidly connected



(*a*) (*b*)

Fig. 18

and act as one piece; this sleeve is clamped in position in the rest *h*, Fig. 17. The index plate *i*, Fig. 18 (*b*), in this case having sixty divisions, or teeth, is held rigidly against a shoulder *j*, which forms part of the socket *k*, by the nurled nut *l*. By use of the swiveling graduated slides *m* and *n*, Fig. 17, the crank handles *o* and *p*, and the lengthwise adjusting screw *q*, cutters of any angle and shape may be cut. The work *r* is supported on milling arbors which fit in the socket *k*, in Fig. 18 (*b*), and differently spaced indexed plates may be supplied as required.

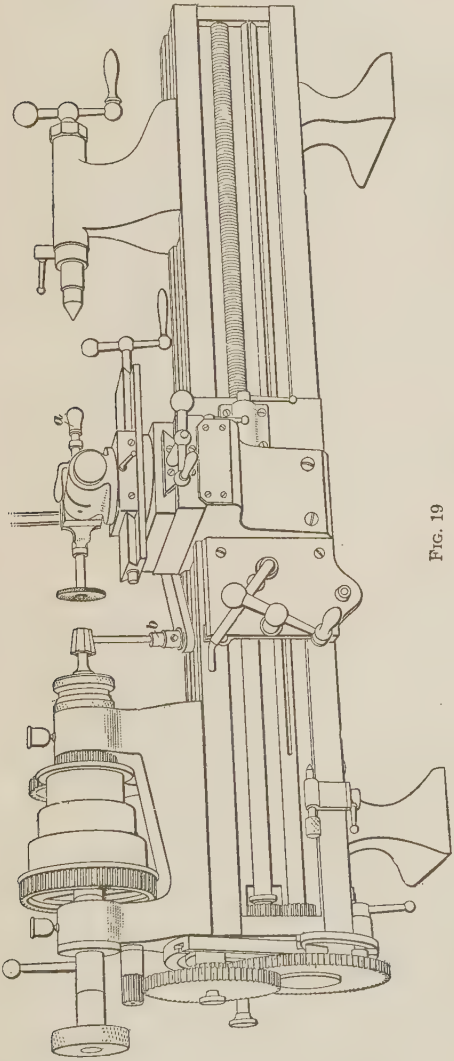


Fig. 19

27. As the average of the large and small ends of the diameters of the cutter is close to $\frac{1}{2}$ inch, the number of teeth to be cut will, in accordance with Art. **14,** be six; and as the index plate has sixty divisions, it should be moved ten divisions to bring the work in such position that each succeeding tooth, in turn, will cut. The angle of the milling cutter *s*, Fig. 17, is determined by judgment and trial.

The teeth on the end *a* of the cutter, Fig. 16, are next cut, resetting the milling attachment for this purpose, after which the teeth on the end *c* are filed to shape. The cutter is now hardened by heating it in a muffle furnace, or inside a piece of pipe in a forge, and quenching the cutting end in an oil bath. The heat in the shank is allowed to draw the temper of the neck of the cutter to a dark-blue color. The cutter should be quenched in water as soon as the dark-blue color appears, so that the temper of the cutting end may not be drawn.

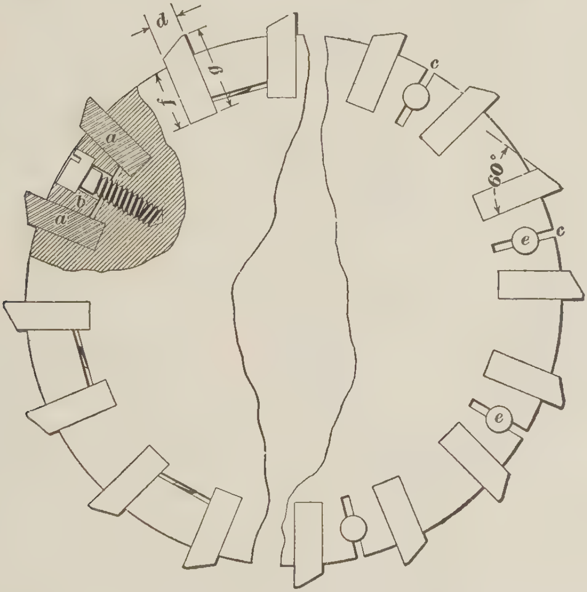
28. The cutter may be conveniently ground on the bench lathe, using the grinding attachment *a*, Fig. 19, with traversing spindle. The cutter is held in a tapered socket which is fitted to the lathe spindle, the teeth of the cutter being supported on the tooth rest *b*. The attachment is first set up to grind the conical part of the cutter and the sides of all the cutters are ground to fit a special gauge at this setting of the machine. After finishing this operation the machine is set up to grind the ends of the cutters and the end teeth of all the cutters are ground.

MILLING CUTTERS WITH INSERTED TEETH

29. Forms.—When milling cutters exceed 6 inches in diameter, the cost of making them of one piece of tool steel becomes rather high; in general, it is cheaper to insert blades of self-hardening or high-speed steel in a body of cheap material, as cast iron or machinery steel. Of a great variety of forms, the simplest that will make a satisfactory cutter is that in which the cutters are fitted to dove-tail slots and driven home after hardening. To make a good job, the cutters must be very carefully fitted, which makes renewal rather expensive. Again, as the slots must necessarily be dovetailed, they are also expensive. These considerations have led to forms that do not require such close and expensive work, although they are not quite as simple.

30. Two standard forms are shown in Fig. 20. In both, the cutters are rectangular in cross-section. Owing to this shape, the slots can be milled very cheaply and cutters to fit them can be made at an expense slight in comparison to that involved in making dovetailed cutters. In the form shown at (*a*), rectangular slots receive the cutters *a* and the body is milled out between every second pair of slots to receive the wedge-shaped piece of steel *b*, which is drawn home by means of the fillister-head screw shown, thus locking the cutters. A space left between the bottom of the piece *b* and the body allows a slight variation in the thickness of the cutters.

In the design shown at (*b*), the metal between every second pair of slots is slotted with a narrow slot *c*. Before cutting the narrow slots, a hole is drilled clear through and reamed tapering to receive the taper pins *e*, which are driven in after the cutters are in place and serve to lock the latter. Driving the taper pins out loosens the cutters sufficiently to allow them to be easily withdrawn.



(*a*) Fig. 20 (*b*)

31. Number of Teeth.—The number of cutting edges for milling cutters with inserted blades may be about as stated in Table II, which is given primarily to aid the toolmaker in selecting a suitable number of cutting edges. The table applies to both carbon- and high-speed-steel cutters; but in the latter case the number of cutting edges may be a little lower than that shown in the table. As opinions differ considerably regarding this matter, it must not be expected that all cutters will conform to the table, which is believed to represent average practice.

32. Proportions.—The proportions of the cutters may be about as follows: Referring to Fig. 20 (*a*), the thickness *d* of the cutter may be about one-fourth the distance from one cutting edge to the next one; the depth *g* may be about three-fourths the pitch of the cutting edges; and the depth *f* of the slots may be about fifty-five one-hundredths of the pitch. By *pitch* is here meant the distance from one cutting edge to the other measured along the arc of the circle circumscribed about the cutter. In other words, the pitch of the cutting edges is equal to the circumference of the cutter divided by the number of teeth. The cutters may be backed off with a milling cutter that will give an angle of 60° between a radial line and the top of the cutter, as shown in the figure. The

TABLE II

CUTTING EDGES FOR MILLS WITH INSERTED CUTTERS

Diameter Inches	Number of Teeth	Diameter Inches	Number of Teeth
6	12	18	35
7	14	20	38
8	16	22	41
9	18	24	44
10	20	26	46
12	24	28	48
14	28	30	50
16	32	32	52

backing off may be carried forwards enough to leave a land of about .03 inch; after hardening and tempering, the cutting edges are finished by grinding the assembled mill in a cutter-grinding machine, giving a relief of about 3°.

33. Rake of Cutting Edges.—In the forms of built-up cutters shown in Fig. 20, no rake is provided for the cutting edges; that is, the cutting edges are radial, as is usually the case when carbon-tool-steel blades are used. Where high-speed-steel blades are employed, rake is sometimes provided. An improved form of high-speed-steel, inserted-blade cutter is shown in Fig. 21. Here the rake angle *a* is 15°; the body of the cutter is made of machinery steel, threaded to fit the milling arbor; the blades *b* are of high-speed steel and butt against setscrews which are supported in the back plate *c* and serve to adjust the teeth endwise in the slots. The blades are securely held in position by the pins *d*, which have a flat milled on them tapering with the center lines of the pins, which are driven into the holes.

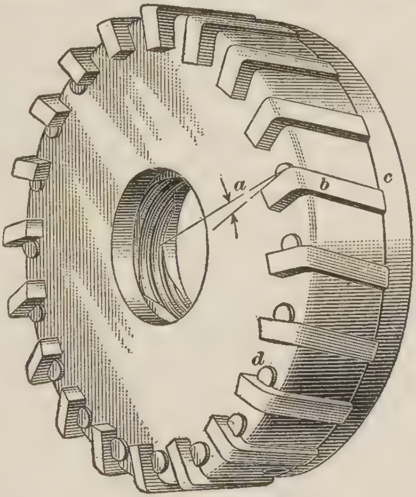


Fig. 21

34. Helical Cutting Edges.—If a helical slot is cut into the body, the cutter tooth must also be helical to fit it. This very expensive shape can scarcely be made with the ordinary machinery found in a tool room. For this reason, straight slots are cut at the required angle, so that straight cutters may be used. Straight cutters set at an angle are open to one serious objection: the front face of the cutter is not radial throughout its length, but changes from a positive rake at one end to a radial face in the middle and then to a negative rake at the other end. A straight cutter inserted at an angle is shown in Fig. 22. To bring out the objectionable point more clearly, the diameter of the body has been made rather small. At the end *a* the face of the cutting edge has a positive rake, as indicated by the face of the cutter being above the radial line *o c*. At *d* the cutting face is radial, as it is in contact with the radial line *o d*. The amount of negative rake at *f* is shown by the cutting face at *e* being below the radial line *o e*.

35. The best way of preventing the variable rake is to mill the cutting face of each tooth with a suitable cutter set to produce a radial face. To allow this to be done, the cutter tooth must either be made thicker throughout, or thickened on the cutting face that projects outside the body.

Before cutting the slots, a helix that will give the cutting edges an angle of about 20° with a plane passing through the axis is selected. The milling machine is geared to cut this helix and the turned blank body is put in the machine. With a scriber clamped to the milling-machine arbor, a helical line is scribed on the surface of the body. This line will then serve as a guide for setting the index head by trial to the angle that will give a straight slot coinciding closely with the helix. Unless the milling machine is so arranged that the index head swivels on the platen, the slots must be cut with an end mill. Many designs of milling machines have a so-called *raising block* to which the index head may be clamped and then swiveled across the platen; the slots can then be cut with a regular axial cutter.

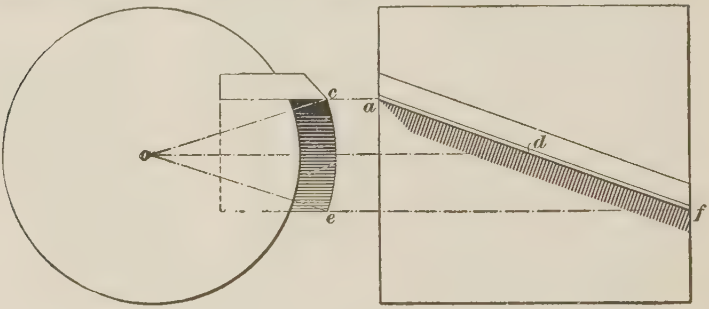


FIG. 22

After the cutters have been inserted into the slots and locked, the milling machine is geared again for the proper helix and the cutting face of each cutter milled helical.

FLY CUTTERS

36. Uses.—A fly cutter is often of great advantage in milling odd shapes or work that cannot be classified as repetition work. Having but a single cutting edge, it is cheaply formed, even if the shape to be milled is quite complex. If properly made, it can be sharpened a number of times without materially changing its shape. Fly cutters are frequently made by filing them to the proper shape; when thus made, it is very difficult to form them so that their shape will not be changed by successive sharpenings. If the method given later is adopted, a satisfactory fly cutter will be produced; a further advantage of this method is that the cutter can always be duplicated at small expense.

A fly cutter must not be expected to cut as fast or wear as long as a regular milling cutter; it will, however, reproduce its shape with great exactness and will be found of great advantage in making and duplicating forming tools of irregular contour for the forming lathe and turret lathe.

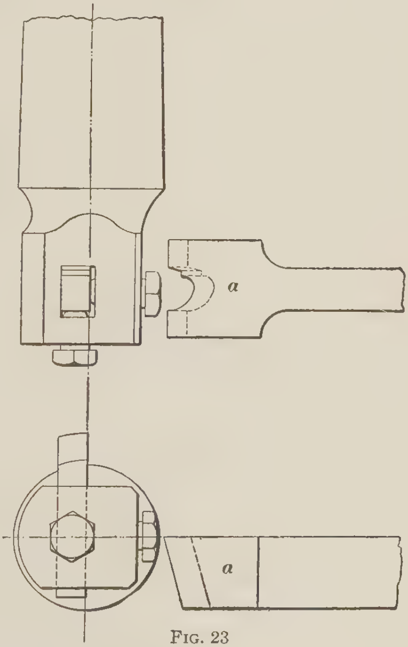


FIG. 23

37. Manufacture.—The first step is to make a forming tool, as *a* in Fig. 23, cutting into its front end the shape that is to be produced by the fly cutter. This may be done in any convenient way; it is usually done by filing. This tool is held in the vise of the milling machine and is so set that its top face is level with the center of the spindle. The soft steel for the fly cutter, which previously may have been roughly filed to shape, is then inserted in the fly-cutter holder and locked. The machine is now started and the forming tool carefully fed against the revolving cutter blank, which is thus cut to the shape of the forming tool. The cutter should not project farther from the holder than sufficient to just allow the forming tool to clear the holder when fed in enough to cut its full shape. The cutter thus formed has no clearance when held in its holder in the position in which it was cut. When set farther out in its holder it will have clearance; and when set farther in, it will have a negative clearance. Grinding a fly cutter thus made will not materially change its shape, as long as it is ground on its front face in such a way that the face remains radial. The cutter should be of sufficient thickness to give a radial front face, as shown in Fig. 23.

FORMED CUTTERS

38. For milling irregular contours on work done in large quantities, formed cutters with teeth shaped to conform to the contour required are in universal use. These cutters are so made that they can be ground on the face of the cutting edges without changing the shape of the contour.

39. Tools for Making Formed Cutters.—Let it be required to make a formed cutter for milling work shaped like the model *a*, Fig. 24 (*a*). A thin steel templet *b* is first filed and scraped to fit the model. A perfect fit will be indicated when no openings can be seen between the templet and the model when they are placed together and held to the light.

A backing-off tool, Fig. 24 (*b*), to be held in the lathe tool post is now made to fit the templet *a*, shown in dotted lines. The top face *b* of the tool is machined so that when set up in the lathe tool post, the plane of its cutting edge will contain the center line of the spindle and be parallel to the ways of the lathe. The front edge *c* of the tool is given clearance by filing and the cutting edge is so finished that no light can be seen between the tool and the templet. The backing-off tool is made of carbon tool steel, is hardened on its cutting end, and its temper is drawn to a straw color.

40. The backing-off tool, Fig. 24 (*b*), must have clearance, but when it is fitted to the templet with its cutting face in the plane of the templet and used with its cutting edge not in the plane of its cutting face and the center line of the spindle, the shape produced by the cutter will not be the shape of the cutter itself. This fact is illustrated in Fig. 24 (*c*) and (*d*). In (*c*), the center gauge *a* is held against a 60° thread with the plane of the center gauge passing through the center line of the screw; in (*d*), the same center gauge is held against the same thread,

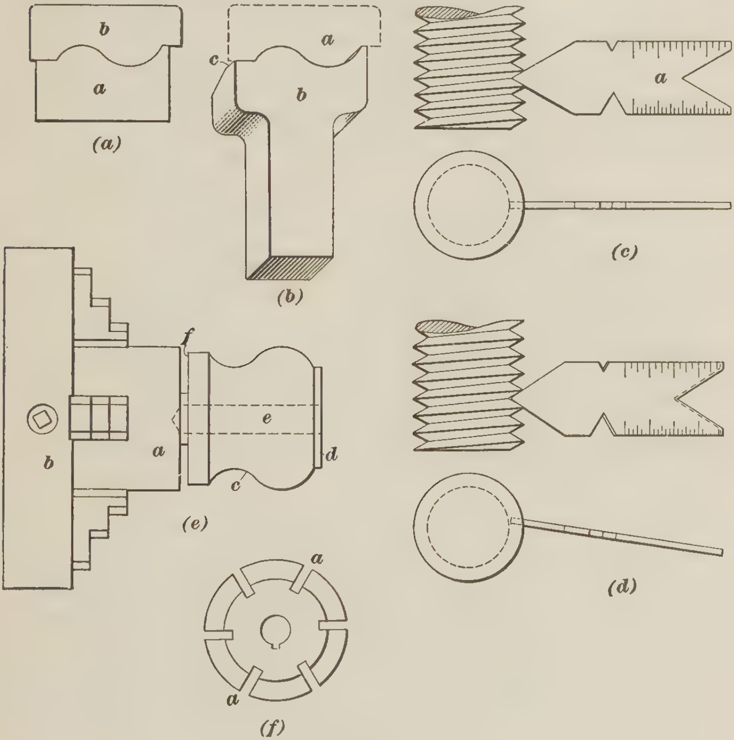


FIG. 24

but with the plane of the center gauge not passing through the center line of the screw. In (*c*) the thread and gauge fit perfectly and in (*d*) they do not fit.

41. Turning and Boring.—A tool-steel bar *a*, Fig. 24 (*e*), of proper diameter is gripped in the lathe chuck *b* and the end of the work is spotted and drilled, but not bored to size. The formed surface *c* of the work is now roughed nearly to shape and size, using any convenient tool, after which it is finished to size with the backing-off tool. In finishing the formed surface, light chips must be taken and a very slow speed must be used to prevent chattering. The end *d* is now faced to size and the hole *e* is bored to within the grinding or lapping allowance of the finished size, after which the work is cut from the bar at *f*, using a cutting-off tool. If the hole *e* had been bored to size after drilling, it would not have been concentric with the formed surface when finished, because the work would have sprung when the formed surface was machined. The work is next forced on a mandrel, and the surface *f* is faced to size.

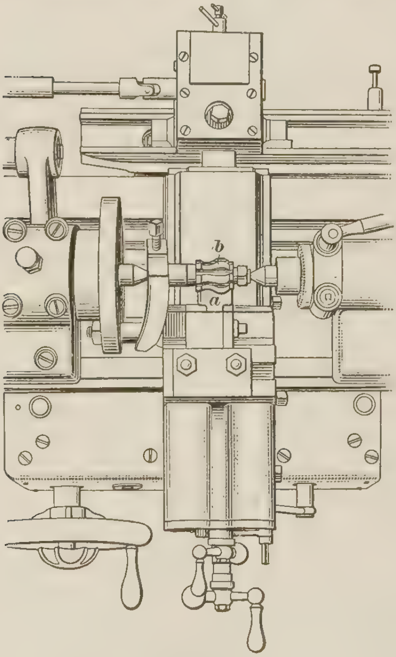


FIG. 25

If the cutter blank had been made by drilling and reaming the hole, forcing the work on a mandrel, and turning the formed surface on it, the work would have turned on the mandrel on account of the width of cut.

42. Milling, Relieving, and Tempering.—The work is left on the mandrel, placed between the milling machine centers, and, using a straight milling cutter, the slots *a*, Fig. 24 (*f*), are cut. A cutter of the shape of the flutes desired is then set up in the machine and the flutes are milled to size. After milling the slots, the cutter blank is placed on a backing-off mandrel, containing a key to prevent the blank from rotating when being backed off. The teeth are then backed off on a lathe, using the relieving attachment, as shown in Fig. 25. The backing-off tool *a* is automatically fed toward the center of the cutter blank *b* while the work is rotating. As soon as a tooth is partly backed off, the tool quickly returns, and starts again toward the center of the cutter. This process is continued until the teeth are relieved up to their cutting edges. The cutter now looks as shown in Fig. 26. It may be hardened by heating it to a red heat in a muffle furnace and quenching in an oil bath. Sharpening a cutter made in this way by grinding it radially on its faces *a* will not change the shape of its teeth.

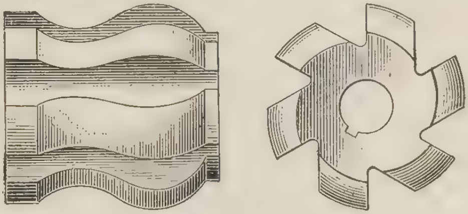
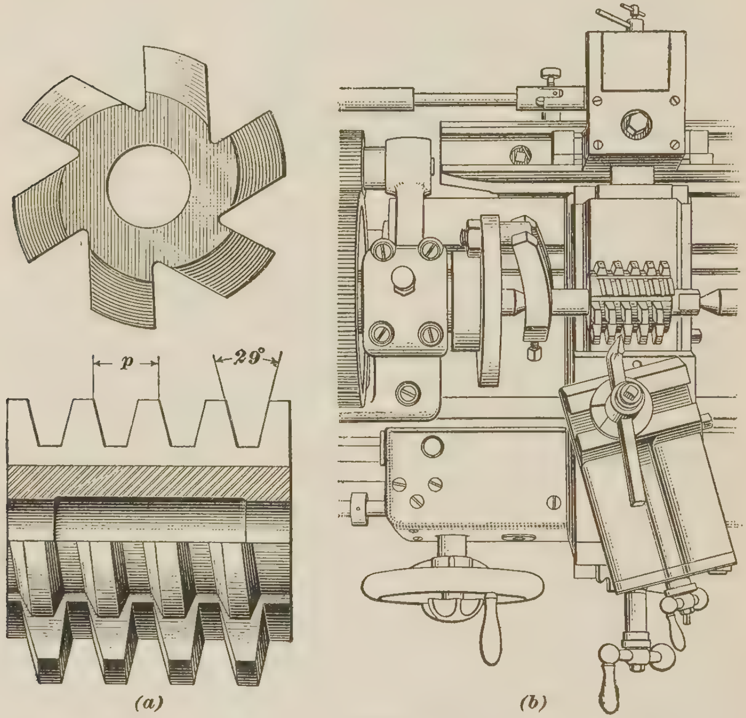


FIG. 26

WORM-WHEEL HOBS

43. Form of Hob.—The hob for cutting the teeth of worm-wheels is a special kind of a milling cutter. It is practically a duplicate of the worm, except that it is made slightly larger in diameter. It is fluted to form cutting edges, as shown in Fig. 27 (*a*). The flutes are sunk in deep enough to go below the bottom of the thread, as shown.

44. Most worms and worm-wheels are made in accordance with the involute system of gearing, the teeth of the worm having the same shape as the teeth of a rack of the same pitch. The angle included between the sides of the teeth is 29°, or each side makes an angle of $14\frac{1}{2}°$ with a plane perpendicular to the axis of the worm. In this system, the whole depth of the tooth, or space for the worm, is found by multiplying .6866 by the pitch; by *pitch* is here meant the distance between corresponding points of adjoining teeth, as the distance p, Fig. 27 (a). The word *pitch* as here employed should not be confounded with the term *lead*, which, when used in reference to a worm, implies the distance that one thread advances in a complete revolution. For a double-threaded worm, the pitch will be one-half the lead and for a triple-threaded worm it will be one-third the lead. Knowing the outside diameter of the worm and the pitch, the diameter across the bottom of the spaces, or inside diameter, is equal to the outside diameter diminished by twice the whole depth of worm-thread. Some toolmakers make the inside diameter of the hob equal to the inside diameter of the worm, while others make it somewhat less. The outside diameter of the hob is found by adding one-tenth the pitch to the



(a) (b)

Fig. 27

outside diameter of the worm. Thus, if the worm is 3 inches outside diameter and .7 inch pitch, the inside diameter of the worm, and also of the hob, is $3-(2\times .6866\times .7)=2.04$ inches. The outside diameter of the hob will be $(.1\times .7)+3=3.07$ inches.

45. Width and Number of Flutes.—The number of flutes should be such that the width of the land at the bottom of the flutes is about equal to the depth of the thread plus .12 inch. To find the number of flutes, divide the circumference corresponding to the inside diameter of the hob by the depth of the worm-thread increased by .12 inch plus the width of the cutter. The width of the round end of the cutter used for fluting the hob may be about $(.17\times \text{pitch})+.12$ inch. Thus, for a hob having a pitch of .7 inch, the cutter may be about $(.17\times .7)+.12=.239$ inch, say $\frac{1}{4}$ inch wide, and the depth of the thread of the worm is $.6866\times .7=.48$ inch. Using a cutter $\frac{1}{4}$ inch wide on the end, the number of flutes will be, for an inside diameter of 2.04 inches,

$$\frac{2.04\times 3.1416}{.48+.12+.25}=7$$

46. Construction.—The construction of a hob is influenced by the work to be done and the manner of doing it. If the hob is to be used in an automatic hobbing machine or gear-cutter, where the blank is mechanically rotated, the number of cutting edges may be reduced. If the blank is gashed and the hob depended on for rotating the blank, a greater number of teeth will be necessary, so that at least two teeth may always be in contact with the blank. Hobs work best when the flutes are at right angles to the thread, instead of being parallel to the axis of the hob. In the former case, each tooth has two equal cutting edges instead of one acute edge and one obtuse edge. When the flutes are parallel to the axis of the work, they should be so cut that the cutting faces of the teeth in the center of the hob are radial.

For large hobs, the body of the hob is sometimes made of cast iron or machinery steel and provided with inserted cutters or teeth. A hob must be at least as long as the portion of the worm that engages any of the teeth of the worm-wheel.

In some cases when the worm-wheel is to be cut in an automatic machine, a short hob is made for roughing and a longer one for finishing. The teeth of the hob may be plugs inserted and fastened with setscrews. The teeth are sharpened by grinding in the flutes with a saucer grinding wheel.

47. Threading and Milling Hobs.—The work is held in the lathe chuck, and it is drilled, threaded, then bored, after which it is cut from the stock. The tool for threading the hob and worm should include an angle of 29°, and be cut off square across, until its width at the end is equal to .31 times the pitch. For the hob under discussion, the end of the tool should be $.31 \times .7 = .217$ inch wide. The tool is ground to fit a Brown & Sharpe worm-thread gauge and the sides of the tool are ground sloping so that they will clear the sides of the thread. The worm-thread is now cut in the same manner as the ordinary screw thread, care being taken to have a sharp and perfectly formed tool for the finishing cuts.

The keyway is now cut and the flutes are milled, a cutter being selected as specified on the drawing, or as determined by trial to produce teeth of the proportions given in Art. **32.**

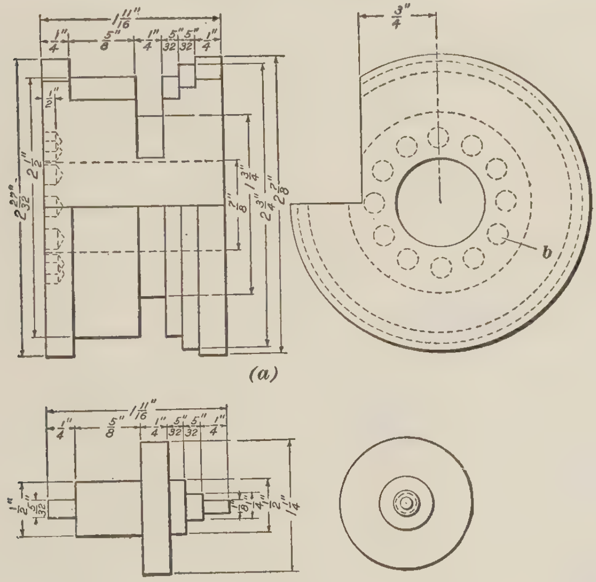
48. Relieving, Tempering, and Grinding.—In order that the hob may cut freely, its teeth must be backed off, or relieved. Placing the hob on the mandrel, having a key to fit the keyway in the hob, the work is taken to a lathe having a relieving attachment, shown in Fig. 27 (*b*), and the machine is geared up to cut a thread of the same pitch and to relieve the teeth. Using a right-hand side tool, one side of the thread is relieved, as illustrated in the figure. After relieving the right side of all the teeth, a left-hand side tool is employed and the left-hand side of all the teeth are relieved. The face of the teeth is next relieved with a finishing tool. Since the bottoms of the teeth do no cutting, they are not relieved.

The cutter is now tempered. If made of carbon tool steel, the hub is heated to a red heat in a muffle furnace and hardened by quenching in an oil bath. If made of high-speed steel, the hob is given the proper heat treatment. The hob is sharpened by grinding radially on the cutting faces.

SCREW-MACHINE, TURRET-LATHE, AND BROACHING TOOLS

CIRCULAR FORMING TOOLS

49. Making a Solid Forming Tool.—Let it be required to make a screw-machine, circular forming tool, Fig. 28 (*a*), of carbon tool steel to turn the work shown in (*b*). If a drawing is provided, the dimensions of the forming tool are given on it; if no drawing is provided, the diameter of the smallest step on the tool may be made equal to twice the diameter of the bore or the diameter of the shaft on which the tool is to be held when in use. The remaining steps are then made larger in diameter than this step by an amount equal to the difference between the largest diameter of the work and each succeeding diameter in turn.



(*a*)

(*b*)

FIG. 28

A piece of 3-inch carbon tool steel is annealed, chucked in the lathe, spotted, drilled, bored to size, and faced on one end. The work is now removed from the chuck, put on a mandrel, rough turned, and the unfinished end is faced to size.

50. The surface having the largest diameter is first turned to size, after which the parting tool, Fig. 29 (*a*), is set to turn the first step by measuring the distance from its side *a* to the end of the work with the micrometer depth gauge *b*, as shown in the figure. As the steps must be undercut for clearance, as illustrated in (*b*), they should be turned a little wider than the finished size and finished to size with the undercutting tool. Whenever possible, the thickness and diameter of the steps are measured with a micrometer caliper. In (*b*) is shown how the thickness of the step may be measured. When the

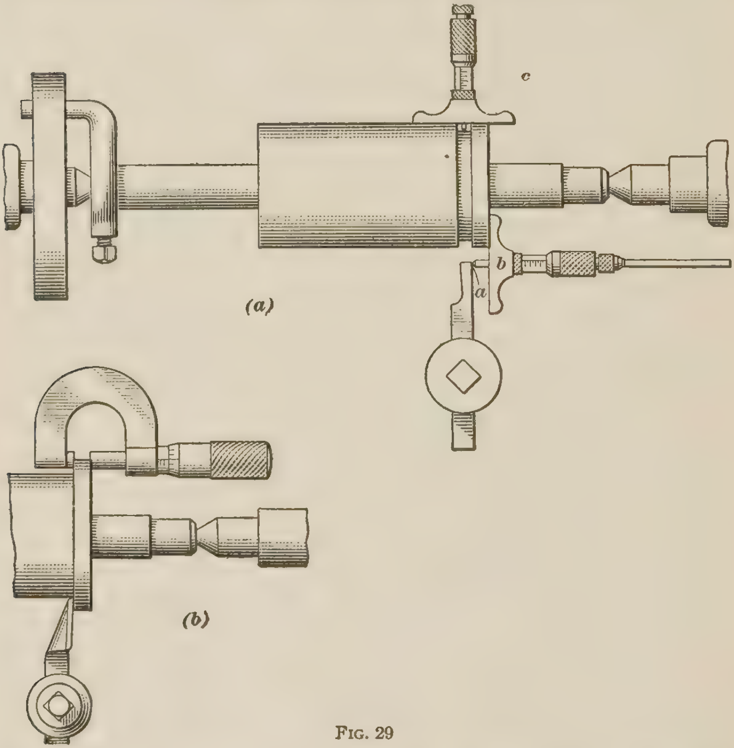


FIG. 29

diameter of the step being turned cannot be measured with a micrometer caliper, a micrometer depth gauge may be employed, as shown at *c* in (*a*). When measured in this way, the depth-gauge reading should be half the difference between the diameter of the step being measured and the step on which the gauge is supported.

51. Holding the work between the milling-machine centers, and using a side milling cutter, the work is milled to provide a cutting face for the tool. When taking the finishing cut, the cutter is set so that it will mill a cutting face, the plane of which will contain the center line of the tool.

When in use, one of the holes *b*, Fig. 28 (*a*), receives a pin contained in the tool holder, which serves to prevent the tool from turning on its shaft. As the tool wears, it is reground until when the succeeding hole receives this pin and the tool holder is adjusted the plane of the cutting edge of the tool will contain the center line of the spindle of the machine on which it is to be used. The first hole is laid out, using dividers and prick punch, so that when fitted to the pin the plane of the cutting face will be near enough to the center line of the spindle of the machine to be within the range of adjustment of the tool holder.

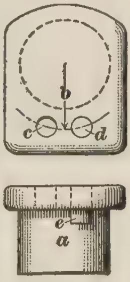


FIG. 30

A drilling jig, Fig. 30, is now made to drill the remaining holes. The part *a* of the jig fits the bore of the tool, the radius *b* of the center line of the holes *c* and *d* is equal to the distance of the first hole drilled in the work from the center line of the work, and the pin *e* is fitted to one of the holes *c* and *d*. In operation, the pin *e* is put in the last hole drilled and the hole *c* serves as a guide when drilling the next hole. After drilling the pin holes, the tool is hardened and its temper is drawn to a straw color, in case the material to be turned is steel.

52. Making a Built-Up Forming Tool.—When the face of the forming tool is very wide, the tool is made of several parts, as shown in Fig. 31. Each of these parts contains a keyway and fits side by side on a shaft. One of the end parts may butt against a shoulder on the tool holder and the other parts be clamped against it by means of a nut working on a thread on the end of the tool-holder shaft.

A piece of round tool steel is chucked in the lathe, spotted, drilled, faced on one end, bored to size, and blanks of the desired thickness are cut from the bar with a cutting-off tool. The keyways are now cut in each piece in turn. A shaper may be used for this operation if a key-seating machine is not available. After this operation is completed on all the parts, the lathe chuck is removed and the centers placed in the machine, being trued up if necessary.

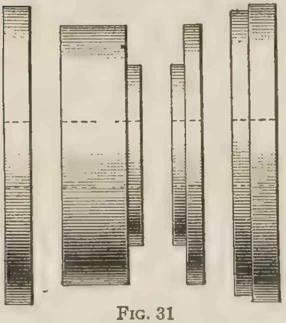


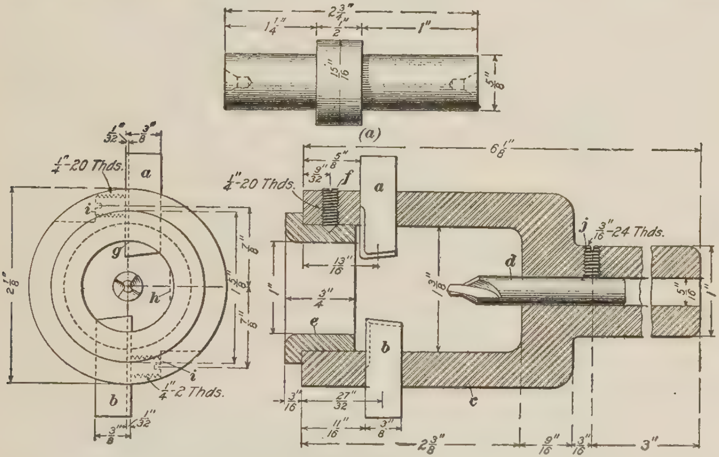
FIG. 31

Each piece is next put on a mandrel, the unfinished end is faced to size, and the outer surface is finished. The work is now keyed and clamped on a special arbor, which may have to be made for the purpose, and milled, so as to form a cutting edge, as in the case of the solid forming tool; and pin holes are drilled in the end of the piece which fits against the end of the bolt or holder carrying the guide pin. The work is now heated to a red heat in a muffle furnace, if made of carbon tool steel, and hardened by quenching in an oil bath. After the edges become worn, the tool is keyed and clamped on an arbor and the cutting face is sharpened.

BOX TOOLS

53. In Fig. 32 (*a*) is shown a working drawing of a piece of work which is to be roughed out on a turret lathe and finished to size on a grinding machine. The work is to be made of cold-rolled machinery steel 1 inch in diameter. In (*b*) is illustrated a box tool used for roughing the surfaces which are $\frac{5}{8}$ inch in diameter, and centering the work. One of the turning tools *a* is set slightly ahead of the other tool *b* and does the rough turning, while *b* takes the finishing cut. The work is to be finished by grinding, for which $\frac{1}{64}$ inch is allowed. The surface, $\frac{15}{16}$ inch in diameter, is not turned on the lathe, the entire amount of metal being removed by the grinder. In operation, one end of the bar stock is roughed nearly to size, centered, and cut off the proper length. After all the pieces are finished to this point, the machine is set up to hold the machined end of the work, the centering tool is adjusted to the proper setting, and the unfinished ends of all the pieces are in turn rough turned and centered. The work is then taken to the grinding machine and ground to size.

54. The body *c* of the tool, Fig. 32 (*b*), may be made first. For this purpose, a piece of machinery steel $2\frac{1}{4}$ inches in diameter and $6\frac{1}{4}$ inches long is cut off and chucked in the lathe.



(*b*) FIG. 32

The work is now spotted; drilled, using a $1\frac{5}{16}$-inch drill, about $2\frac{3}{8}$ inches deep; turned on the outside to a diameter of $2\frac{1}{8}$ inches; bored on the inside to a diameter of $1\frac{3}{8}$ inches; and drilled and reamed through the shank to receive a combination drill and countersink *d*, having a diameter of $\frac{5}{16}$ inch. The work is next reversed in the chuck, adjusted till the outer turned surface runs true, and the shank is turned to size. The bushing *e* may now be made out of a piece of tool steel. The stock is chucked in the lathe, spotted, drilled, turned to size, and bored, after which it is cut off. The bushing is made a snug fit in the body of the tool. While the bushing is in position in the tool body, the

$\frac{3}{16}$-inch hole for the screw f is drilled, the drill being allowed to extend into the bushing a little way, as shown. The drilling is done on a sensitive drill press, the work being held on a **V** block. This depression drilled in the bushing, together with the screw f, serves to hold the bushing in position during operation. The bushing is now heated to a red heat in a muffle furnace and hardened by quenching in water. Its temper is not drawn.

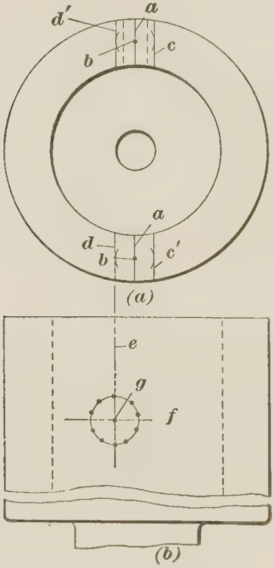


FIG. 33

55. The next operation is to lay out, drill, and file the $\frac{3}{8}$-inch square holes which receive the cutting tools. The end of the work is chalked, and, using the center square, a center line a, Fig. 33 (a), is scribed on it. Light prick-punch marks b are now made on this line, and the dividers are set to $\frac{1}{2}\times\frac{3}{8}-\frac{1}{32}=\frac{5}{32}$ inch, the distance the center lines of the cutters a and b, Fig. 32 (b), are from the center line g. Using the prick-punch marks as centers, arcs are scribed on the end of the work. The lines $c\,c'$ and $d\,d'$, Fig. 33 (a), are scribed tangent to these arcs.

In order that the drill shall not run out when starting, a small drill is first put through. The larger drill will follow the hole made by this drill. A line e, Fig. 33 (b), is next drawn on the surface joining line d of (a), using a key-seat rule or try square. With the hermaphrodite calipers set to $\frac{27}{32}$ inch, the line f in (b) is scribed on the work and a prick-punch mark g is made at the intersection of e and f. With the dividers set to $\frac{3}{16}$ inch and using g as a center, a circle is scribed on which several prick-punch marks are made. Similarly, the work is laid out for the other cutter on the opposite side, working from the line c.

56. The work is now clamped to a **V** block on the drill-press table so that the lines c and d, Fig. 33 (a), will in turn be square with the table. Using a $\frac{3}{8}$-inch drill and chipping the centers of the holes should the drill not start centrally, the holes are drilled. After drilling, the holes are chipped and filed square to receive the tools.

Using the milling machine, a $\frac{1}{2}$-inch wide flat *h*, Fig. 32 (*b*), is milled on the shank of the tool, holding the shank in the vise of the machine; and the spots *i* are milled on the body of the tool with an end mill, the work being held either in the vise or the chuck on the dividing head. Using a $\frac{3}{16}$-inch drill the holes *i* are drilled; and using a No. 28 drill, the hole *j* is drilled. All the holes are now tapped, the bushing and setscrews are put in place, a combination drill and countersink is secured in the tool shank, and cutters of self-hardening or high-speed steel are fitted to the work. The tool is now completed.

BROACHES

57. Making Square Broach.—In Fig. 34 is shown a broach for $\frac{3}{4}$-inch square holes. This broach may be made of carbon tool steel, although broaches are sometimes made of special alloy steels. The last three teeth of the broach are made .0005 inch oversize, owing to the fact that a broach will cut a little undersize. A piece of $1\frac{1}{8}$-inch round stock is cut off about $4\frac{1}{8}$ inches long and carefully annealed. The ends of the work are now faced square and the parts *a*, *b*, and *c* are turned to size.

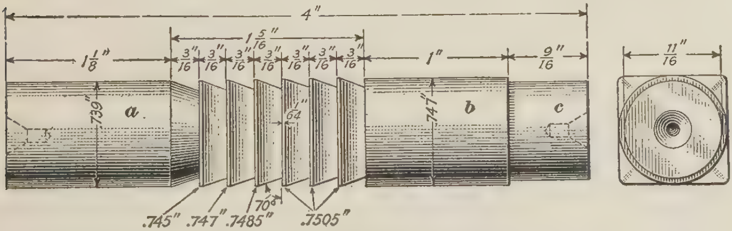


FIG. 34

The work is next set up on the milling machine, the dividing head and a 70° angular cutter being used. Each tooth is, in turn, milled to the dimensions given in the illustration. The tool is then heated to a red heat in a muffle furnace and hardened by quenching in oil. The teeth are sharpened by honing their faces with an oil stone.

58. Making Set of Square Broaches.—Suppose a set of broaches, Fig. 35, are to be made to cut a ½-inch square hole. The pieces of carbon tool steel, out of which the broaches are to be made, are carefully annealed and centered, the guides *a* are turned to size, and the parts *b* and *c* are finished by turning.

The central portion *d* of the starting broach, second broach, and third broach are now turned to size, as shown in the end views *e*, *f*, and *g*, Fig. 35. The work is next set up between the milling-machine centers and the central portion of all the broaches is milled ½ inch+.002 inch square. After squaring up the work, the rising block *a*, Fig. 36, is put on the milling-machine table and the index head *b* is secured to it. The chuck is put on the index head and the work *c* is held in it as shown. A 70° angular cutter *d* is secured to the arbor *e*, and the clearance spaces *i*, Fig. 35, are milled to size.

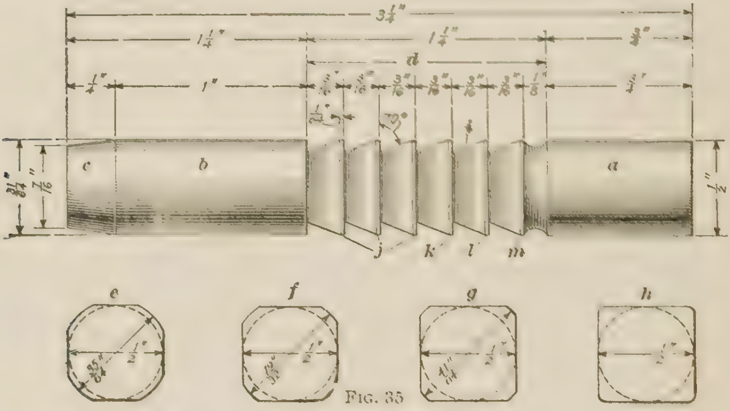


FIG. 35

59. On the lathe centers, the lands *j*, Fig. 35, of the starting, second, and third broaches are turned $\frac{35}{64}$ inch, $\frac{19}{32}$ inch, and $\frac{41}{64}$ inch, respectively, and the lands *k*, *l*, and *m* are turned .015, .030, and .045 inch, respectively, less than these values.

The work is again set up on the milling-machine centers and a $\frac{1}{4}$-inch end mill is secured to the spindle of the machine. The cutting faces *j*, Fig. 35, of the starting broach *e*, the second broach *f*, and the third broach *g* are milled $\frac{1}{2}$ inch square; the faces *k*, $\frac{1}{2}-.015$ inch square; the faces *l*, $\frac{1}{2}-.030$ inch square; and the faces *m*, $\frac{1}{2}-.045$ inch square; the cutting faces *j* of the finishing broach *h* are milled $\frac{1}{2}+.001$ inch square; the faces *k*, $\frac{1}{2}-.015$ inch square; the faces *l*, $\frac{1}{2}-.030$ inch square; and the faces *m*, $\frac{1}{2}-.045$ inch square. The clearance spaces are filed by hand where needed, and the work is hardened by heating it to a red heat in a muffle furnace and quenching in an oil bath. The cutting faces are sharpened by honing with an oilstone.

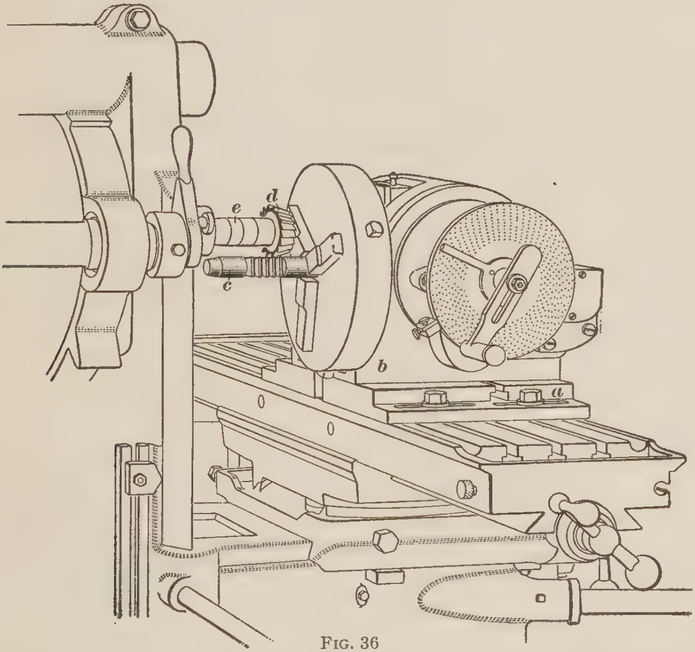


Fig. 36